Social Costs of Purchasing and Installing Entrainment Reduction Technologies: Ameren Missouri Labadie Energy Center

Final Report

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1. Overview

This document evaluates the social costs of entrainment reduction technologies at the Labadie Energy Center (LEC). By social costs, the U.S. Environmental Protection Agency (EPA) means

> … costs estimated from the viewpoint of society, rather than individual stakeholders. Social cost represents the total burden imposed on the economy; it is the sum of all opportunity costs incurred associated with taking actions. These opportunity costs consist of the value lost to society of all the goods and services that will not be produced and consumed as a facility complies with permit requirements, and society reallocates resources away from other production activities and towards minimizing adverse environmental impacts (79 *Fed. Reg.* 158, 48432).

Reducing entrainment can generally be accomplished by altering operations, closing the facility, or by purchasing, installing and operating entrainment reduction technologies. Installing and operating entrainment reduction technologies would lead to physical changes and financial effects that give rise to opportunity costs. When monetized, these are social costs. Social costs from entrainment reductions can arise from several sources (Electric Power Research Institute [EPRI] 2015; Bingham and Kinnell 2014):

Compliance Costs—the owner's cost for purchasing, permitting, installing, operating and maintaining entrainment reduction technologies.

- Government Regulatory Costs—permitting, monitoring, administering, and enforcing regulatory compliance.
- Power System Costs—increased fuel costs from running more expensive units when the facility is subject to outage, capacity reductions, or closure due to the implementation of entrainment-reducing technologies.
- Environmental Externalities—changes in environmental quality such as those to water flow, noise, emissions, and viewsheds.
- Economic Impacts—unit closures and electricity price increases.

The analysis conducted for LEC includes quantitative estimates for Compliance Costs, Government Regulatory Costs, and Power System Costs as listed above. Wood (2019) and Burns and McDonnell (2018) have considered several alternative screen, water reuse, and closed-cycle cooling technologies and have evaluated the following options as potentially feasible at LEC:

- 2.0mm dual-flow fine mesh screen (FMS) conversion
- 0.5mm FMS in an expanded cooling water intake structure (CWIS)

- Closed-cycle mechanical draft cooling system retrofit.

1.1 Summary of Social Costs

The first step in estimating social costs is to determine whether the entrainment reducing technology costs will result in the plant becoming uneconomic to operate. A premature shutdown of the plant would have social costs related to loss of jobs, loss of income and expenditures, loss of tax base, increased electricity costs due to generation being dispatched at a higher price from less efficient plants, and increased infrastructure costs to maintain grid reliability. Installing entrainment reducing technologies at LEC to comply with EPA's Section (§) 316(b) Final Rule represents an additional cost of operations that would most likely be passed onto Ameren Missouri's electric customers in the form of higher rates. These costs will need to be recovered in future rate case filings. The plant's significance in Ameren Missouri's generating portfolio suggests that only an extraordinarily expensive conversion requirement would lead to premature closure. Therefore, this analysis assumes Ameren Missouri will incur the entrainment reducing compliance costs and continue to operate the LEC plant.

The social costs of installing entrainment reduction technologies are estimated by determining the design, construction and installation costs of the evaluated technologies along with the operation and maintenance (O&M), power system, externality, and government regulatory costs. The analysis assumes that all compliance costs would be passed on to Ameren Missouri's electric customers. Table 1 summarizes the results of this evaluation and its implication for social costs.

Following the requirements of the rule, Table 1 evaluates social costs under two discount rates: 3 and 7 percent (79 *Fed. Reg.* 158, p. 48428). As the first column of Table 1 shows, the top half of the table presents the present value of social costs discounted at 3 percent, and the bottom half presents the social costs discounted at 7 percent. The next column of the table presents each of the feasible compliance options evaluated at LEC. The third and fourth columns present the total compliance costs estimated for each option. The third column presents the estimated design, construction, and installation costs, and the fourth column presents the annual O&M costs for each feasible option.

The remaining columns in the table present the individual categories of social costs developed for this analysis: electricity price increases from compliance and power system costs, externality costs, and government regulatory costs. The analysis discounts the future stream of each of these social costs at the relevant discount rate and sums them over the years they are specified to occur to develop the Total Social Cost estimate presented in the penultimate column.

The table concludes by presenting the Annualized Social Cost estimate for each technology. The annualized estimate is calculated using the equation:

$$\textit{Annualized cost} = \frac{r(NPV)}{1-(1+r)^{-n}} \tag{1}$$

Where r is the discount rate and n is the number of years for which the analysis is conducted.

Table 1
Total Engineering & Social Costs of Feasible Technology Options at LEC

		Compliance Costs[a]		Social Costs (Present Value)					
				Electricity Price Increases Resulting From					
Discount Rate	Technology Type	Total Design, Construction, & Installation Costs	Annual O&M Costs	Compliance Costs	Power System Costs	Externality Costs[b]	Government Regulatory Costs	Total Social Costs	Annualized Social Costs
3%	Closed-Cycle Cooling Retrofit	$431.9M	$15.1M	$494.0M	$98.0M	—	$0.074M	$592.1M	$30.21M
	2.0mm Dual-Flow FMS	$19.5M	$0.28M	$16.2M	—	—	$0.003M	$16.2M	$0.83M
	0.5mm FMS	$48.9M	$0.49M	$37.0M	$2.7M	—	$0.009M	$39.7M	$2.02M
7%	Closed-Cycle Cooling Retrofit	$431.9M	$15.1M	$255.8M	$51.3M	—	$0.061M	$307.1M	$24.75M
	2.0mm Dual-Flow FMS	$19.5M	$0.28M	$8.8M	—	—	$0.003M	$8.8M	$0.71M
	0.5mm FMS	$48.9M	$0.49M	$20.1M	$1.4M	—	$0.007M	$21.6M	$1.74M

[a] Compliance costs presented in Table 1 are undiscounted and in 2019 dollars. The social costs associated with each technology are discounted at 3 and 7 percent using the specifications outlined in Table 2.

[b] The analysis does not include quantified estimates of the social costs resulting from externalities. Externality costs include decreases in social wellbeing resulting from property value, recreation, human health, reliability, and water consumption impacts. These categories of social costs were beyond the scope of this analysis.

Compliance costs are specified as occurring over a 30-year time period for a cooling tower retrofit and over a 30-year time period for FMS. Power system costs are specified to occur during construction, based on outage impacts, and during operation, based on efficiency and auxiliary load impacts. Regulatory documents will be submitted in 2019, and the timing for activities related to installation are dependent on the technology being installed. The engineering study for a closed-cycle cooling system retrofit at LEC specifies a 96-month project to complete the permitting, design, construction and installation for all four units (Burns and McDonnell 2018). Table 2 reflects the timing specifications for each of the alternatives evaluated.

Table 2
Timing Specified for Feasible Technologies at LEC

Entrainment Reducing Technology	Regulatory Documents Submitted	Permitting, Design, Construction & Installation	O&M Costs Begin	Years of Technology Operation
Closed-Cycle Cooling System Retrofit:				
Unit 1	2019	2020–2023	2024	30
Unit 2	2019	2020–2024	2025	30
Unit 3	2019	2020–2025	2026	30
Unit 4	2019	2020–2026	2027	30
2.0mm Dual-Flow FMS	2019	2019–2023	2024	30
0.5mm FMS	2019	2019–2023	2024	30

As Table 1 shows, the social costs of each technology include the option's compliance costs, the additional power system costs that would be incurred with each technology, the externality costs of each technology, and the governmental regulatory costs. As previously noted, the analysis specifies that all compliance costs are passed on to Ameren Missouri's rate payers resulting in increased electricity prices. To develop the electricity price increases, the design, construction, and installation costs are allocated over the specified construction and installation time-periods presented in Table 2. Operation and maintenance costs are then added for each year the technology is operational, and the future stream of those costs are discounted by 3 and 7 percent to develop the present value estimate for each discount rate. The social costs of compliance costs are discussed in more detail in Section 2.

Power system costs represent the additional power needed to operate the new technologies and the additional fuel needed from running less efficient units during installation construction outages. The power system costs are developed from evaluating backpressure and auxiliary load effects, capacity losses from each of the technologies with estimated outage times, and electricity consumption associated with each technology. Details of the power system cost estimates are presented in Section 3.

Externality costs represent the environmental impacts associated with the installation of entrainment reducing technologies. Potential impacts could affect recreation, property values, water consumption, reliability, and human health. This analysis is beyond the scope of this study and are not included in the social cost estimates.

Governmental regulatory costs include the total costs associated with permitting, monitoring, administering, and enforcing the technology selection and installation. The social costs of government regulatory costs are discussed in more detail in Section 2.

2. The Social Costs of Compliance and Governmental Regulation Costs

This section describes the methods used to estimate the social costs associated the compliance costs of designing, constructing, installing, permitting, operating, and maintaining entrainment reduction technologies. The section also describes the method for estimating the social costs associated with governmental costs of permitting, monitoring, administering, and enforcing regulatory compliance.

2.1 Social Costs of Compliance Costs

As Figure 1 shows, expenditures on entrainment reduction technologies would have implications for Ameren Missouri's balance sheet and construction activities. Balance sheet implications would accompany the purchase, installation and operation of any of these entrainment reduction technologies. Balance sheet implications are transmitted through financial, electricity, and regulatory markets to register as social costs (i.e. consumer and producer surplus) to groups that potentially include shareholders, ratepayers, and the general population. How these are realized as social costs depends upon the regulatory and market environments.

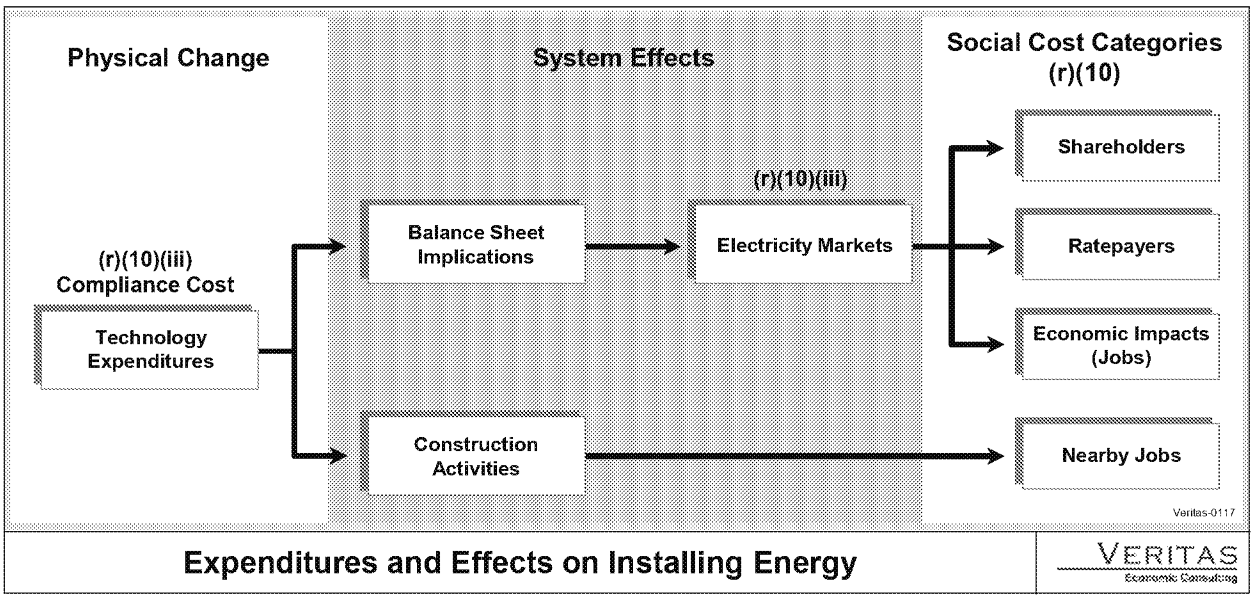


Figure 1: Social Costs Associated with Technology Expenditures

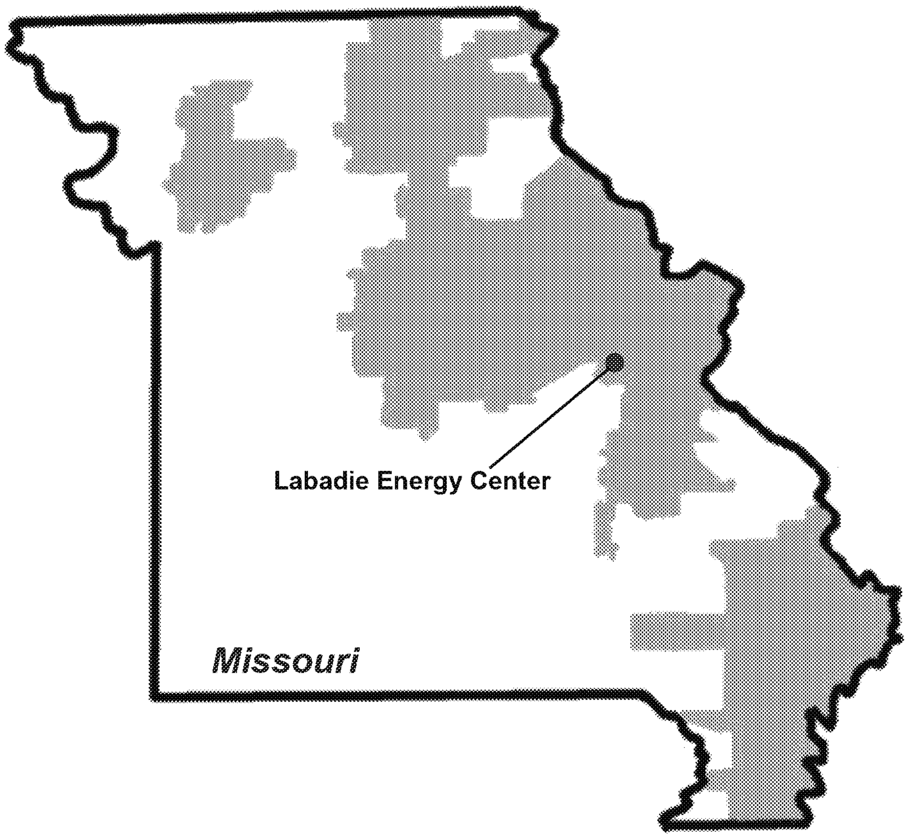
In addition, as the figure depicts, construction generates nearby economic activity, which can lead to good social outcomes such as more jobs. These economic impacts can be studied via economic input-output analysis techniques. As related local outcomes are typically considered good, they are not measured under social costs and not considered further here.

LEC is owned and operated by Ameren Missouri, a regulated, investor-owned public utility that is a subsidiary of the Ameren Corporation (Ameren 2019). Ameren Missouri generates, transmits, distributes and sells electricity in central and eastern Missouri. Over 1.2 million residential, commercial and industrial electric customers are served in 64 counties (Ameren 2019). Ameren Missouri's assets include approximately 10,300 MW of nuclear, coal, natural gas, oil, hydroelectric and renewables generating capacity (Ameren 2019). Figure 2 presents Ameren Missouri's electric service territory and location of LEC (Ameren 2019). Figure 3 illustrates Ameren Missouri's generation portfolio fuel type (Ameren 2016).

Ameren Missouri is potentially eligible to recover the costs of installing entrainment reduction technologies. Since installing entrainment-reducing technologies is a regulatory environmental compliance requirement, these costs are expected to be passed on to customers in the form of higher rates. The Missouri Public Service Commission (MPSC) is the governing body that regulates the operations of Ameren Missouri and the setting of rates. The MPSC holds hearings to review requests and can approve authorization for cost recovery (MPSC 2019). Procedures involved in rate request hearings include allowing intervener comments and Ameren Missouri rebuttals. This process, along with the permitting itself, results in costs to the government, which are Government Regulatory Costs.

Ameren Missouri's recent rate case history is instructive with respect to the implications of an additional rate increase. On July 31, 2018, Ameren Missouri announced a $167 million rate cut reflecting the federal tax reductions passed by Congress last December. The rate cut equates to a 6 percent decrease in customer's electric bills. The rate reduction is part of Ameren Missouri's new Smart Energy Plan that contains incentives for economic development, grid modernization, solar energy, and energy efficiency programs. The plan also includes a rate freeze through April 2020 as well as rate caps that will limit the size of future rate increases. Ameren Missouri's electric rates are among the lowest in the nation and are the lowest of any investor-owned utility in Missouri (Ameren Missouri 2018).

The costs associated with new entrainment reduction technologies could potentially lead to a rate increase filing causing electricity price increases for customers. Table 3 lists the average cost of electricity, electricity use, and monthly electric bill for residential customers in Missouri for 2017 (U.S. Energy Information Administration [EIA] 2017). The table also lists the percentage of household income spent for electricity at selected household income levels (U.S. Census Bureau 2017).



Source: Ameren Missouri 2019

Legend

Ameren Missouri Territory

Ameren Missouri Service Territory

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Figure 2: Ameren Missouri Electric Service Territory

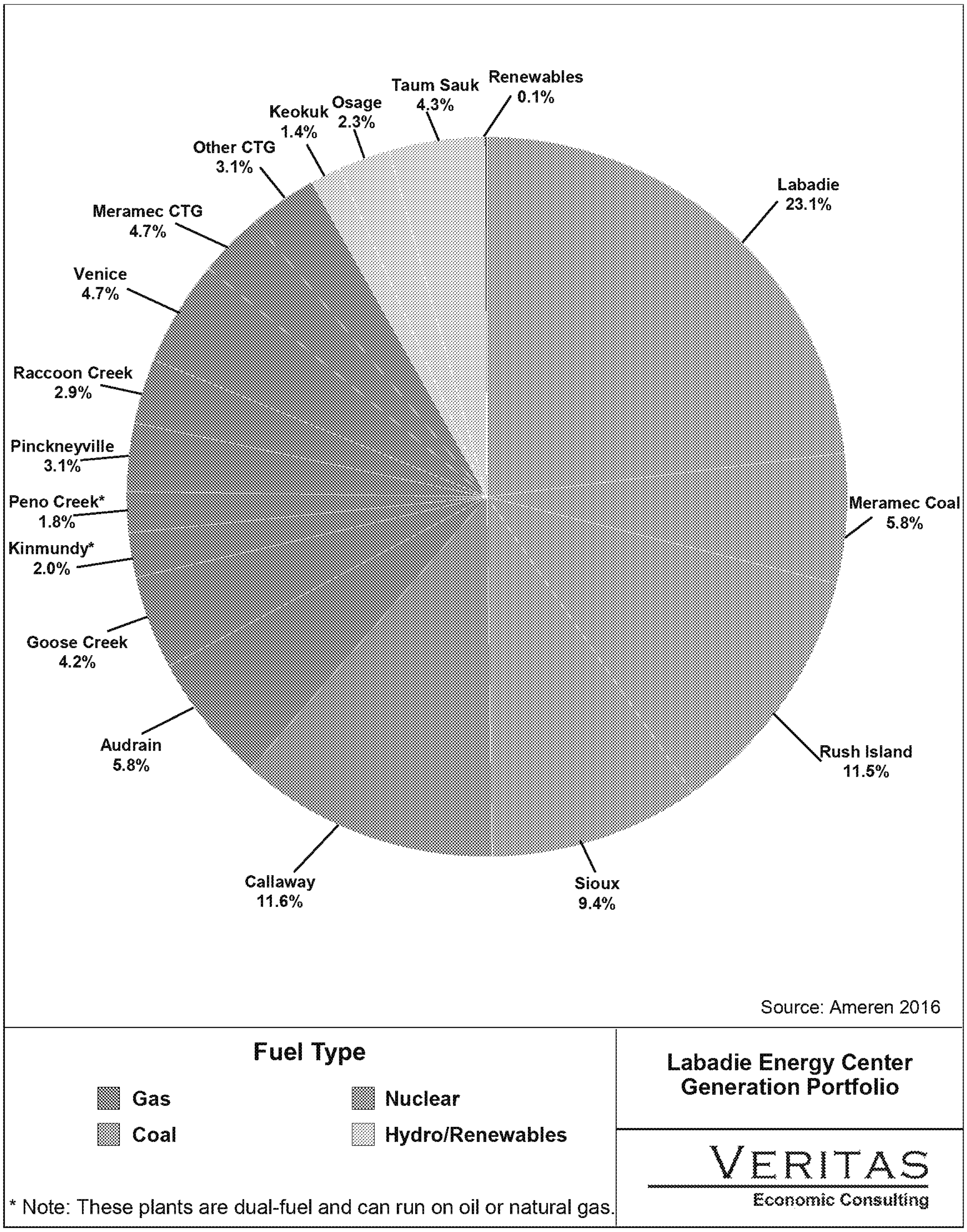

Figure 3: Ameren Missouri Generation Portfolio Fuel Type

Residential electricity rates in Missouri were the 19th lowest among U.S. states in 2017 (U.S. EIA 2017). Although the burden of electricity expenditures is relatively low for many Ameren Missouri customers, many households spend a significant portion of their income on electricity.

All households would share the burden; however, lower-income households would experience a proportionately larger impact.

Table 3
2017 Residential Cost and Use of Electricity and Its Percentage of Household Income in Areas Served by Ameren Missouri

Category	Missouri
Average cost of electricity per kWh	$0.1163
Average use of electricity in kWh per month	994
Average monthly bill	$115.60
Median annual income	$53,578
Percentage of annual household income needed for electricity (monthly bill x 12):	
$5,000 annual income	27.7%
$12,500 annual income	11.1%
$20,000 annual income	6.9%
$30,000 annual income	4.6%
$50,500 annual income	2.7%
$62,500 annual income	2.2%
$87,500 annual income	1.6%
$125,000 annual income	1.1%
$175,000 annual income	0.8%
$200,000 annual income	0.7%

Source: U.S. EIA (2017); U.S. Census Bureau (2017)

For households, the implications of higher electricity prices depend on the price elasticity of demand for electricity. Price elasticity refers to the amount that quantity demanded changes with price. The EIA estimates that when the price of electricity increases by ten percent, aggregate electricity use decreases by two percent to three percent in the short run (elasticity of -0.2 to -0.3) and three percent to five percent over multi-year periods (elasticity of -0.3 to -0.5).[1]

In the billing context, if a customer with an elasticity of -0.2 who spends $100 ($0.10/kWh x 1000 kWh) per month on electricity in baseline conditions experiences a 10 percent increase in electricity rates, the customer would reduce use by 2 percent to 980 kWh. This would result in a monthly bill of $107.80 and an annual increase in electricity expenditures of $93.60 ($7.80 x 12).

[1] Price Responsiveness in the AEO2003 NEMS Residential and Commercial Buildings Sector Models," Steven H. Wade (2003). http://www.eia.gov/oiaf/analysispaper/elasticity/pdf/buildings.pdf.

Two effects occur that relate to changes in the customer's wellbeing. First, the customer has decreased electricity use by 240 kWh (20 kWh x 12) over the course of a year. For context, this is equivalent to not operating a typical 5 kW air conditioning unit for 48 hours in a year. By not doing this, the household loses the utility of a cooler environment. The monetized willingness to pay of this lost utility is one component of social costs from the electric rate increase. The second component is the cost of having to pay more for using less electricity.

The second effect is that the household incurs $93.60 in increased electricity costs. Under the conventional (neoclassical) economic theory applied here, households spend money to maximize their utility. For example, when anglers choose among fishing sites or diners among restaurants, they pick ones that give them the greatest happiness relative to costs. This measure of happiness, referred to as willingness to pay, is greater than their expenditures. For example, a consumer taking a $100 trip or paying $100 for dinner at a restaurant would have a higher willingness to pay than the $100 expenditure. For illustrative purposes, the consumer's total willingness to pay could be $140. This means that the consumer gained $40 in consumer surplus, the value over and above the $100 that the consumer had to pay for the trip or dinner.

An activity-specific investigation of consumer surplus to expenditure ratios has not been conducted for this analysis. However, an important result of optimizing time and expenditures over some fixed period is that the relative marginal values of expenditures are equated.[2] An implication is that if the example person chose to spend $100 on a restaurant trip or consumer good those expenditures would return something like $140 in value. Because the example household has foregone $24 in electricity use (240 kWh x $0.10/kWh), the equating of relative value indicates this is $33.60 in forgone value from electricity use.

For this illustrative household, a ten percent price increase results in a social cost of $33.60 in electricity use and $131.04 ($93.6 x 1.4) in forgone enjoyment from goods and activities due to increased electricity expenditures. In total the social cost is $164.64 ($131.04 + $33.60).

The magnitude of these additional increases could also lead to economic impacts that can accompany electricity price increases (Deschenes 2010). Changes in electricity prices can lead to economy-wide employment impacts through their effect on residential and business electricity consumers. For business electricity impacts, the commercial and industrial sectors are all major users of electricity as an input to production. Electricity price increases would raise the costs of

[2] Neoclassical theory posits that utility of an activity/good over a time period diminishes as the amount of the activity/good increase. An implication is that amounts of activities/goods are purchased so that a dollar spent on one activity/good returns the same value as a dollar spent on another activity/good.

providing final goods and services in these sectors. The analysis does not quantify this effect on other sectors of the economy.

2.2 Social Costs of Governmental Regulation Costs

Government regulatory costs include the total costs associated with permitting, monitoring, administering, and enforcing the technology selection and installation. Costs are incurred by the government as the permitting and review process is undertaken. These vary with the type of technology as certain technologies require substantially more permitting. Those with more significant environmental effects would have higher permitting costs. These costs are initially borne by the government but ultimately paid by taxpayers.

Government regulatory costs are developed from U.S. EPA's estimates in the Economic Analysis document developed for the 2014 Rule (U.S. EPA 2014). Following Table 7-7 in U.S. EPA's Economic Analysis document (U.S. EPA 2014), government administrative costs (regulatory costs) are specified to be 0.02 percent of compliance costs.

3. Social Costs of Power System Effects

The U.S. EPA's 2014 § 316(b) Rule (79 *Fed. Reg.* 158, 48300–48439) (hereafter Rule) requires that applicants submit studies of technologies or operational measures that can reduce entrainment. Section § 316(b) (r)(12) Non-Water Quality Environmental and Other Impacts Study requires a study and "detailed facility-specific discussion of the changes in non-water quality environmental and other impacts" attributed to technologies or operational measures considered under § 316(b)(r)(10). The non-water quality environmental and other impacts as defined in the Rule are:

(i) Estimates of changes to energy consumption

(ii) Estimates of air pollutant emissions and of the human health and environmental impacts associated with such emissions

(iii) Estimates of changes in noise

(iv) A discussion of impacts to safety

(v) A discussion of facility reliability

(vi) Significant changes in consumption of water

(vii) A discussion of all reasonable attempts to mitigate each of these factors.

This (r)(10) report focuses on estimating the social costs associated with changes in energy consumption, § 122.21 (r)(12)(i), and offsite emissions, § 122.21 (r)(12)(ii). The other listed § 122.21 (r)(12) requirements are covered in the (r)(12) report. Energy consumption and emissions impacts arise from plant outages for technology installation, additional electricity consumption required to operate the technology, and unit-efficiency changes related to warmer cooling water temperatures.

3.1 Overview of Power System Effects

Power system effects can arise from several sources. As depicted in Figure 4, shutdowns and construction outages lead to system-level efficiency and capacity changes. Significant capacity reductions can affect system reliability, which can have social costs. Electrical system reliability effects are a factor that Directors may consider in determinations (§ 125.98(f)(3)(iv) May Factor 4—Reliability Impacts).

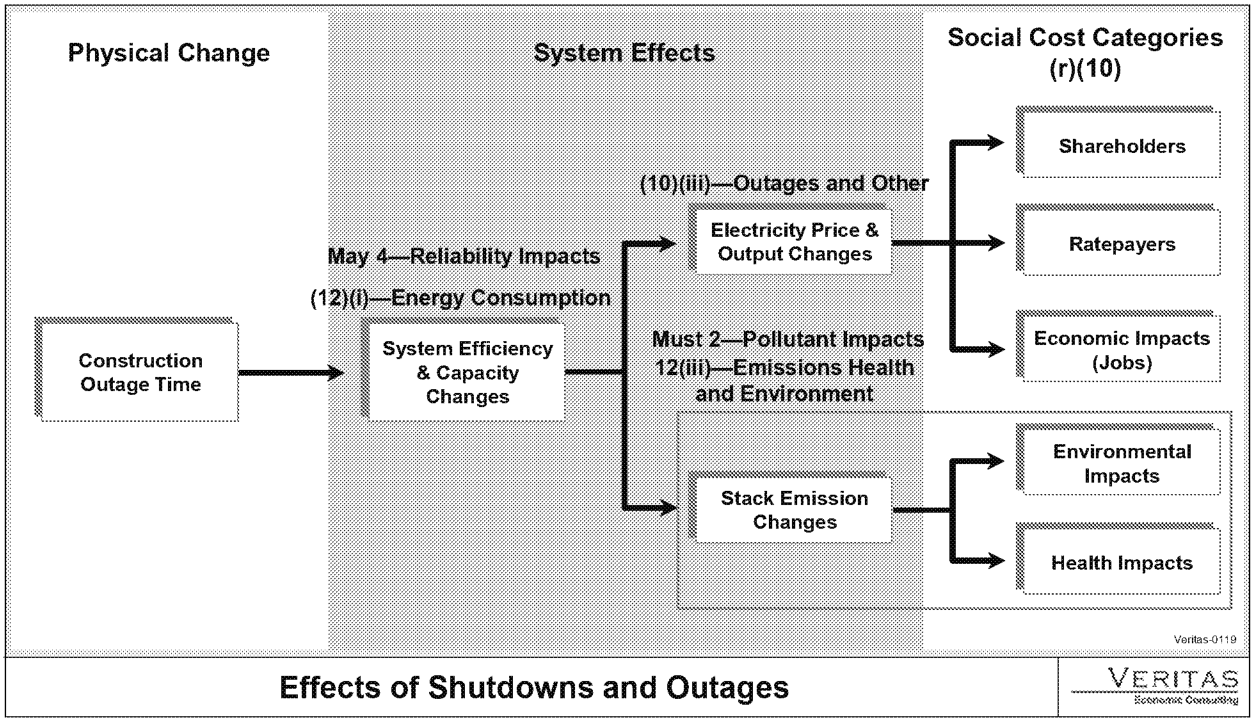

Figure 4: Effects of Shutdowns and Outages

Shutdowns and outages lead to less efficient dispatch and changes in energy consumption. These are to be assessed under § 122.21(r)(12)(i)—Energy Consumption. Changes in energy consumption will impact electricity production costs, leading to social costs that must be quantified in § 122.21(r)(10)(iii)—Outages Other.[3] Also, the re-dispatch associated with system-level efficiency changes leads to stack emission changes which are to be studied under (r)(12)(ii)—Emissions Health and Environment. These emissions are a factor that Directors are required to consider (§ 125.98(f)(2)(ii) Must Factor 2—Pollutant Impacts).

Certain other effects become important once entrainment reduction is underway. These are most pronounced with cooling towers but also occur with other technologies. As depicted in the figure, cooling towers require electricity to operate and can reduce the efficiency of generation. This leads to changes in net electrical generation capacity and downstream effects that are

3 "Outages Other" refers to the component of (r)(10)(iii) which requires that, "…only that portion of lost net revenue [from any outages, downtime, or other impacts to facility net revenue] that does not accrue to other producers can be included in social costs."

discussed in the preamble and with evaluation requirements that are the same as those that arise from outages and shutdowns.[4,5]

Old and inefficient units could potentially be subject to economic shutdown rather than incurring expensive retrofit costs. In previous efforts, EPRI has independently and with owner input identified shutdowns as occurring when the present value of conversion exceeds the present value of closing (i.e., NPV of conversion < $0) (Bingham, Mathews, and Kinnell 2009; EPRI 2011a). LEC provides baseload electricity for Ameren Missouri's electric customers, providing approximately 23.1 percent of total load (see Figure 3). The plant's operational significance suggests that only an extraordinarily expensive conversion requirement would lead to premature closure. Therefore, this analysis assumes Ameren Missouri will incur the entrainment reducing compliance costs and continue to operate the LEC plant.

The next most important capacity effect comes from outages. Outages happen when facilities are unable to access cooling water during equipment installation. This occurs during certain undertakings, such as expanding an existing intake or connecting to cooling towers.

Connecting supply and return lines to the towers would require that the units be off-line. For the conceptual level design conducted for the (r)(10) submission, there was no basis available to determine the required outage time with any precision. According to Burns and McDonnell (2018), the downtime for each unit is specified to be 2 to 4 weeks.

Certain other effects become important once entrainment reduction is underway. These can occur with most approaches but are typically more pronounced with cooling towers. As depicted in Figure 5 below, when operated, cooling towers can increase condenser backpressure and require additional auxiliary equipment load to operate. This leads to net electrical generation capacity and efficiency effects. These effects result in energy consumption that must be identified under (r)(12)(i)—Energy Consumption. As with outages, these energy consumption changes result in changes to social costs and stack emissions. The Rule requires a "detailed" and peer-reviewable assessment of related effects under (r)(12)(i)—Energy Consumption and (r)(12)(ii)—Emissions Health and Environment. These are also factors that Directors must consider

4 "… the social cost of the energy penalty is the cost of generating the electricity that would otherwise be available for consumption except for the energy penalty. Again, an assessment of these costs would be determined under the § 122.21(r)(10) demonstration" (79 *Fed. Reg.* 158, p. 48370).

5 "EPA's review of emissions data … suggests that impacts from these pollutant discharges could be significant. These include the human health and welfare and global climate change effects—all associated with a variety of pollutants that are emitted from fossil fuel combustion" (79 *Fed. Reg.* 158, p. 48341).

(§ 125.98(f)(2)(ii) Must Factor 2—Pollutant Impacts). Moreover, there is significant discussion in the preamble indicating the importance of related effects.[6,7,8,9]

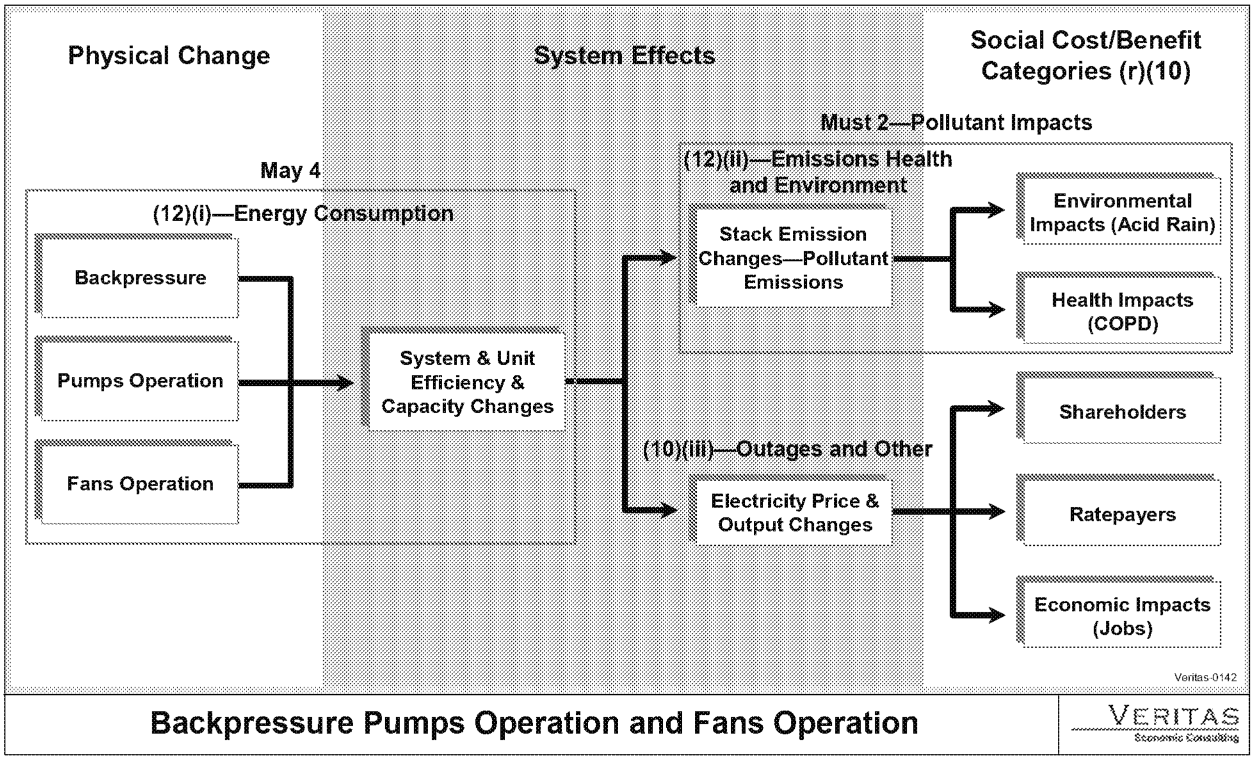

Figure 5: Effects of Pumps and Backpressure

The engineering evaluation estimates that a total of 25.040 MW of additional pumping power is required for the pumps under a closed-cycle cooling retrofit (Burns and McDonnell 2018). This electricity would be required whenever the unit is operating. Approximately 12.4 MW of existing auxiliary load would be decommissioned, resulting in net pumping load of 12.64 MW. In addition, another 14.91 MW is required to operate the fans during summer and 8.95 MW is required in the winter. There is an additional 1.35 MW of other auxiliary load that is required for processes such as raw water makeup pumps and chemical feed pumps (Burns and McDonnell

6 "... the social cost of the energy penalty is the cost of generating the electricity that would otherwise be available for consumption except for the energy penalty. Again, an assessment of these costs would be determined under the §122.21(r)(10) demonstration" (79 *Fed. Reg.* 158, p. 48370).

7 "EPA's review of emissions data ... suggests that impacts from these pollutant discharges could be significant. These include the human health and welfare and global climate change effects—all associated with a variety of pollutants that are emitted from fossil fuel combustion" (79 *Fed. Reg.* 158, p. 48341).

8 "While both of these factors contribute to increased air emissions, the larger contributor to projected increased air emissions is by far the energy penalty" (79 *Fed. Reg.* 158, p. 48341).

9 "EPA is not able to quantify the frequency with which facilities could experience these local impacts, and therefore has concluded that the proper forum to address such local impacts fully is in a site-specific setting" (79 *Fed. Reg.* 158, p. 48342).

2018). When there are important efficiency effects, these lead to variable hourly unit-level efficiency changes and system-level cost and emission impacts.

3.2 Power System Concepts

Net generating capacity effects are best understood and quantified in the context of power system operations. LEC is owned and operated by Ameren Missouri, a regulated, investor-owned public utility that is a subsidiary of the Ameren Corporation (Ameren 2019). Ameren Missouri generates, transmits, distributes and sells electricity in central and eastern Missouri. Ameren Missouri participates in the Midcontinent Independent System Operator (MISO) regional transmission organization. Headquartered in Carmel, Indiana, MISO provides electric reliability and coordination services in geographically defined local resource zones across fifteen states and Manitoba, Canada. Ameren Missouri participates in MISO's integrated marketplace where generation is bid into the power market and dispatched at least cost to participating members. Figure 6 shows LEC in relation to Ameren Missouri and MISO's geographic coverage area. LEC's connection to this region indicates that the power market that would be most affected by outages and efficiency changes at LEC is the Ameren Missouri Market Region.

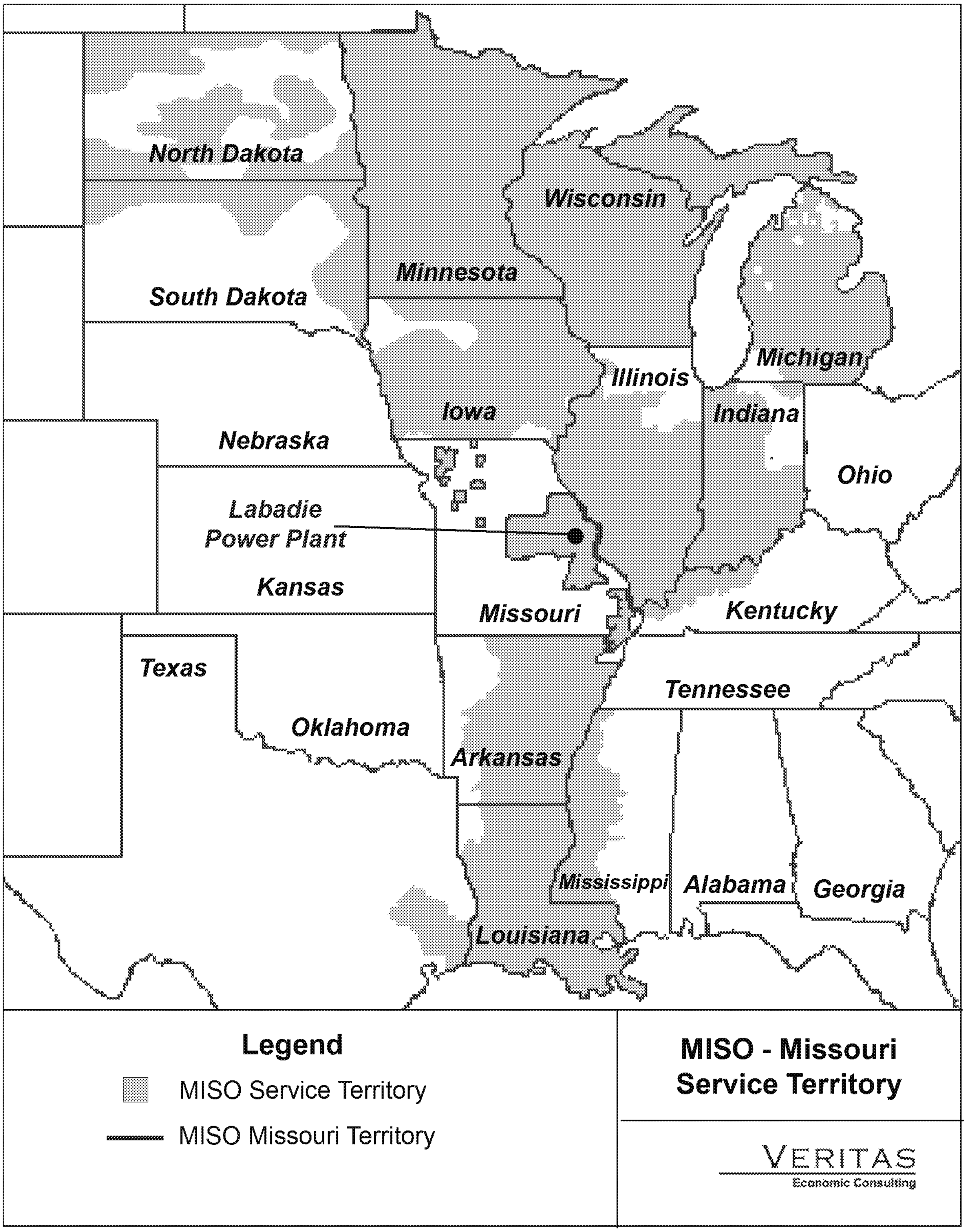

Figure 6: LEC in Relation to Ameren Missouri and MISO

To offset capacity losses from installing and operating entrainment-reduction technologies, Ameren Missouri would employ the most cost-effective and feasible combination of operating its own units more intensively and purchasing additional electricity from independent power producers. To estimate the power system effects from capacity losses, the relevant Baseline and Counterfactual conditions are specified and input into the Ameren Missouri module of Veritas' Environmental Policy Simulation Model (EPSM) (Veritas Economics 2011), a 316(b)-focused power system model. Figures 7 and 8 present an overview of this modeling process.[10] In these figures, the vertical bars represent generating units. Their height is their marginal cost, and width represents capacity. The figures represent an individual hour out of the 8,760 hours in a year. System electrical load for that hour is represented by the green line.

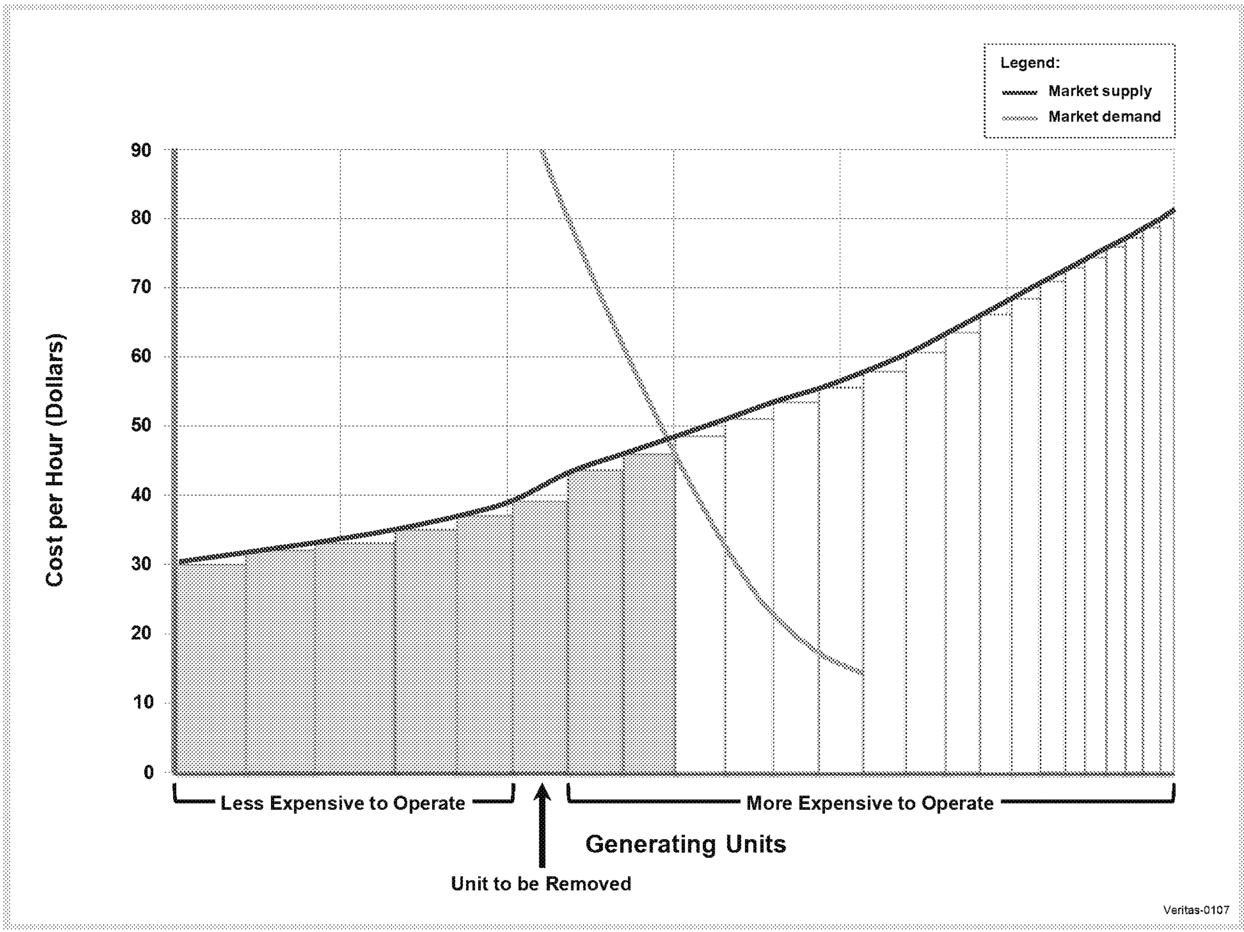

Figure 7: Electricity System under Baseline Conditions

Figure 7 represents market outcomes under Baseline conditions. The marginal cost of generation is where load intersects the dispatch order (slightly below $50 per MWh for illustration purposes). The dispatched units (in grey) all produce electricity at this price or less. The units

[10] The Baseline and Counterfactual modeling structure is the EPA-endorsed methodology for conducting benefit-cost analysis (U.S. EPA 2010).

that are not dispatched (in white) are all more expensive to operate. The total cost of meeting load is represented by the area of the shaded units. An operating unit (or equivalently an amount of generating capacity) that is to be taken off-line is identified.

Figure 8 depicts the power system outcomes when this previously operating capacity is no longer available. As this figure indicates, when a previously operating generation capacity is removed from the stack, more expensive to operate units "shift" to the left. Some of this capacity must operate to meet the existing load (which is fixed in this one-hour example).

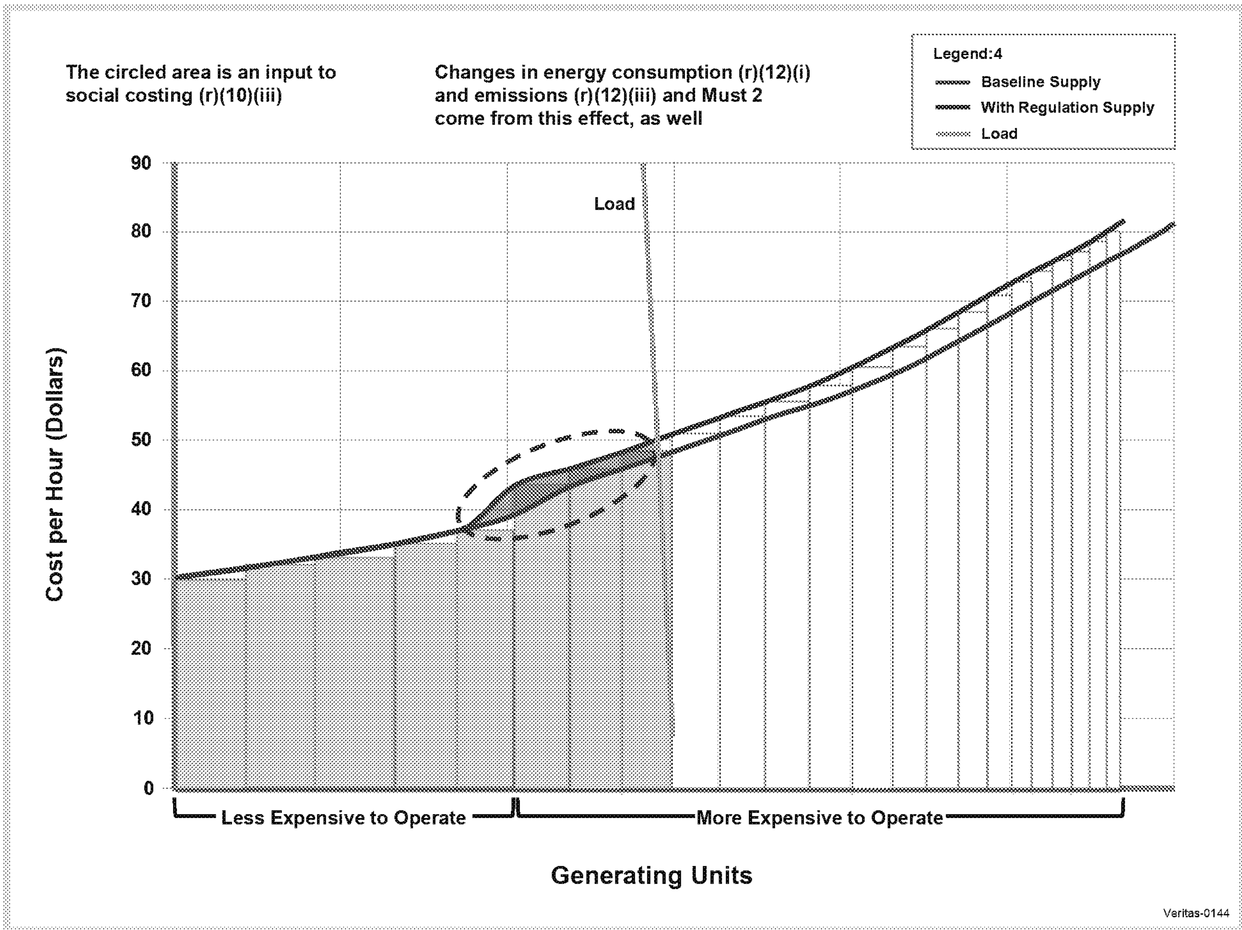

Figure 8 Electricity System Under With-Regulation Conditions That Reduce Capacity

During other time periods (not pictured), load moves up and down. Power is more expensive to generate at all load levels above the generation cost of the previously operating unit (slightly under $40 in Figure 8). Additional outcomes include changes in fuel consumption and emissions as different units operate.

The overall impact is an increased cost of electricity to the consumer, which is a social cost resulting from use of cooling towers. However, because they occur in the context of price effects in competitive markets, this means there are financial transfers that make it difficult to identify who bears the social costs. Specifically, the figure above also indicates that with lost output from LEC (from both conversion outages and capacity losses) there would be an increase in the average electricity price in the Ameren Missouri Region. Knowing that LEC has to incur a conversion outage and will incur capacity losses, organizations selling into the Ameren Missouri Region can possibly expect to receive higher prices for their electricity, and entities purchasing electricity from competitive markets within the Ameren Missouri Region could potentially experience higher wholesale electricity prices.

The implications of these price changes vary by organizations. Distribution utilities, municipalities, and cooperatives would endeavor to recover costs through rate increases. Commercial and industrial purchasers would experience reduced profitability. Governmental cost increases would ultimately be passed on to taxpayers.

The costs associated with new entrainment reduction technologies would be additional costs that could potentially lead to another rate increase filing which would result in higher prices for residential, commercial, and industrial customers. The magnitude of these additional increases could also lead to economic impacts that can accompany electricity price increases (Deschenes 2010). Changes in electricity prices can lead to economy-wide employment impacts through their effect on residential and business electricity consumers. For business electricity impacts, the commercial and industrial sectors are all major users of electricity as an input to production. Electricity price increases would raise the costs of providing final goods and services in these sectors. Changes in LEC's power delivery would be reflected in some of these customers.

3.3 Power System Simulation

The effects of outages for equipment installation, auxiliary loads, and unit closures are evaluated by modeling them within the context of Ameren Missouri power and economic systems. This is accomplished by developing counterfactual specifications that include construction outages and auxiliary load. The basis for the evaluation is Burns and McDonnell (2018) evaluation, which specifies that the per unit downtime ranges from 2 to 4 weeks.

In the modeling context, the capacity at Units 1 through 4 are set at zero over the specified outage period. In the subsequent, post-conversion and operation years, capacities are adjusted to reflect auxiliary loads occurring after the modeled conversions. With capacity adjusted in this manner, a power system simulation model (Environmental Policy Simulation Model [EPSM]) is operated and differences in operations across Baseline and With Outage conditions are evaluated (Veritas Economics 2011). EPSM is populated with data from two main data sources: the Continuous Emission Monitoring Systems (CEMS) and the Emissions & Generation Resource Integrated Database (eGRID). CEMS provides hourly readings of emissions and generation of coal-powered power plants in the United States and is available on the USEPA's website at ftp://newftp.epa.gov/DMDnLoad/emissions/hourly/monthly/2016/. eGRID provides annual data on power plant generation and emissions and is available on the USEPA's website at https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid.

The CEMS data includes descriptive variables such as the plant's facility code, plant name, unit ID, the date and hour each reading was taken, and how much of each hour the unit was running. The data set also contains variables on the generation and emissions readings for each unit including generation load in megawatts, SO2 emitted in pounds, SO2 rate in pounds per MMBtu, NOx rate in pounds per MMBtu, NOx emitted in pounds, CO2 emitted in tons, CO2 rate in tons per MMBtu, and heat input in MMBtu. Unit-specific particulate matter rates are not available and are specified to be 0.0044 lbs/MMBtu. The data are organized by year, state, and month.

The eGRID data are organized by year, state, and plant. EPSM uses the following two specific eGRID data sources:

- Unit year 2016 data, which gives readings for individual units of a plant
- Generator year 2016 data, which gives readings for generators in each plant.

The Unit dataset provides unit descriptors, the unit's operational status, the primary fuel type, annual readings of heat input in MMBtus, annual NOx emissions in tons, annual SO2 emissions in tons, and CO2 emissions in tons. The Generator dataset provides the same descriptor variables, as well as the generator nameplate capacity in megawatts, generator capacity factor, and generator annual net generation in megawatt hours. For EPSM's purposes, the Unit and Generator data sets are merged together based on the facility code and generator/unit ID to provide one set of data for each unit that describes the units fuel type, heat input, nameplate capacity, capacity factor, and annual net generation. Finally, Missouri data is used to represent the generation of all the operating units in the Ameren Missouri Region.

The conceptual process described in Section 3.2 is implemented for LEC by carrying out the following steps within EPSM's Ameren Missouri power system module:

1. Estimate the hourly energy penalty

2. Specify total hourly load.
3. Operate model consistent with load and unit characteristics.
4. Create scenarios representing LEC's conversion and ongoing operations.
5. Run EPSM to identify counterfactual dispatch.
6. Calculate differences in fuel consumption, emissions, and costs.

These steps are implemented as follows.

3.3.1 Estimate Hourly Energy Penalty

The energy penalty evaluation is an important input to several studies necessary for the § 122.21(r)(12) report and also social costs that must be studied under § 122.21(r)(10). Energy penalties arise from "slightly lower generating efficiency attributed to higher turbine backpressure when the condenser is not replaced with one optimized for closed cycle operation when retrofitting existing units" (79 *Fed. Reg.* 158, 48341). Studying energy penalty effects is important because:

(1) They relate directly to energy consumption, which must be studied under (r)(12)(i).

"The study must include the following: Estimates of changes to energy consumption, including but not limited to auxiliary power consumption and turbine backpressure energy penalty" (§ 122.21(r)(12), 79 *Fed. Reg.* 158, page 48428).

(2) They produce indirect and direct social costs, which must be studied under (r)(10).

"EPA is using energy penalty to mean only the opportunity costs associated with reduced power production due to derating (turbine backpressure)" (79 *Fed. Reg.* 158, 48370).

"… the social cost of the energy penalty is the cost of generating the electricity that would otherwise be available for consumption except for the energy penalty. Again, an assessment of these costs would be determined under the § 122.21(r)(10) demonstration" (79 *Fed. Reg.* 158, 48370).

(3) They affect air emissions, which must be studied under (r)(12)(iii).

"…increased air emissions … due to the energy penalty" (79 *Fed. Reg.* 158, 48341)

"The study must include the following: … Estimates of air pollutant emissions and of the human health and environmental impacts associated with such emissions. (79 *Fed. Reg.* 158, 48428)

(4) These air emissions lead to environmental, health, and social cost (welfare effects), which must be studied under § 122.21(r)(12)(iii) and (r)(10):

"…due to the energy penalty when retrofitting to cooling towers" related to "human health, welfare, and global climate" (79 *Fed. Reg.* 158, 48341).

"Estimates of air pollutant emissions and of the human health and environmental impacts associated with such emissions" (79 *Fed. Reg.* 158, 48428).

The required studies under (r)(12) are described as "a detailed, facility-specific discussion." Both (r)(10) and (r)(12) reports are subject to peer review (79 *Fed. Reg.* 158, 48368). Energy efficiency impacts result in important social costs and can also be an important determinant in their own right. For example, decision-makers looking ahead to greenhouse gas requirements may find these effects and their costs more important than comparable capital costs.

Unlike losses from operating pumps and fans, the energy penalty effect is difficult to generalize. Energy penalties on the hottest days of summer can be higher (EPRI 2011b; U.S. Department of Energy Office of Electricity Delivery and Energy Reliability 2008). An important consideration is that energy penalty effects vary hourly and tend to be at their worst when atmospheric conditions are already leading to high air conditioning loads, generation costs, and wholesale electricity prices.

3.3.2 Energy Penalty Study Approach

The temperature of cooling water affects turbine performance. Generally speaking, colder cooling water improves efficiency (EPRI 2011b). Energy penalty effects are due to the different cooling water temperature of cooling towers compared with that of once-through waterbody temperature. With once-through cooling, the cooling water is the temperature of the source waterbody. With closed-cycle cooling, the cooling water temperature is related to cooling tower design characteristics and atmospheric conditions, in particular wet-bulb temperatures.

As wet-bulb temperatures increase, units cooled by wet closed-cycle recirculating systems become less efficient. As noted by EPA, "the cost may be incurred by the facility … or by another generating unit" (79 *Fed. Reg.* 158, 48370). Fossil facilities can "over-fire" to compensate for efficiency impacts. Depending upon operational considerations, these facilities may experience increased fuel costs and less dramatic capacity reductions.[11] Generally speaking, capacity reductions are experienced when fuel input is at the boiler rated maximum and/or unit backpressure at the highest tolerated point. At this point, fossil units cannot increase Btu input, and therefore experience capacity reductions. Nuclear units cannot vary fuel input. In both cases, costs (and environmental effects) of providing lost electricity are incurred by other units.[12]

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[11] An important consideration is that both electricity prices and cooling tower performance are correlated with wet-bulb temperatures.

[12] When cooling towers result in lower cooling water temperatures, the opposite occurs.

Figure 9 depicts the generalized approach for identifying efficiency effects from a closed-cycle conversion. The approach uses the baseline and counterfactual structure recommended in U.S. EPA (1991) *Guidelines for Preparing Regulatory Impact Analysis*. The baseline (red) input-output curve has output limited by line 1 and input (in BTUs) limited at line 2 (number of BTUs per kilowatt hour.) With an energy penalty from operating the cooling tower, the new input-output curve is represented by the blue line. If the unit cannot over-fire, the output is limited to where line 2 intersects the blue curve as indicated by line 3. Auxiliary load increases as cooling tower fans are operated. This is modeled as the shift in capacity to line 4. The original fuel input is maintained to serve the parasitic load. The resulting input-output curve (5) represents reduced efficiency and lost net capacity.

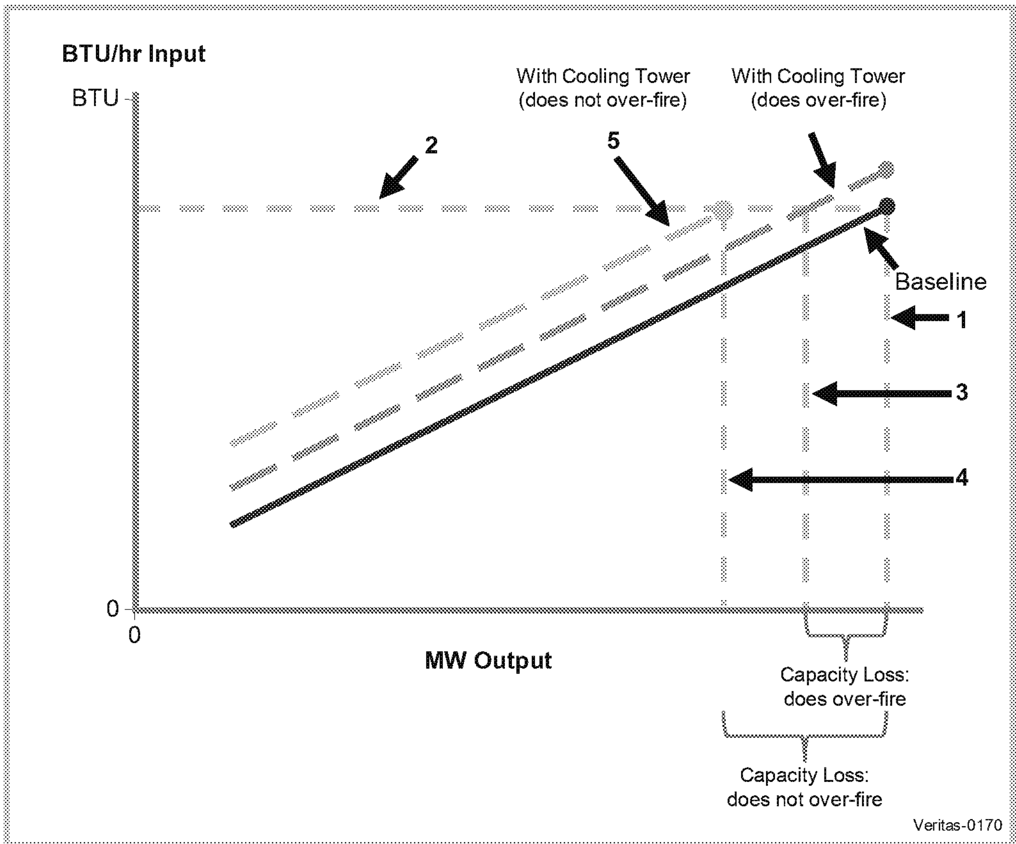

Figure 9: Potential for Efficiency Effects from Closed-Cycle Cooling

Because atmospheric conditions vary hourly, these curves move up and down. Figure 10 depicts the energy penalty effect for time periods when the source water body water is cooler than the cooling tower water. As depicted in the figure, the magnitude of the energy penalty depends upon fixed (time invariant) technical factors including the slope of the turbine back pressure curve and cooling tower design parameters. The energy penalty also depends upon factors that vary somewhat predictably over the course of a year including source waterbody temperatures and wet bulb temperatures. To evaluate this effect, these are combined in baseline and counterfactual simulations.

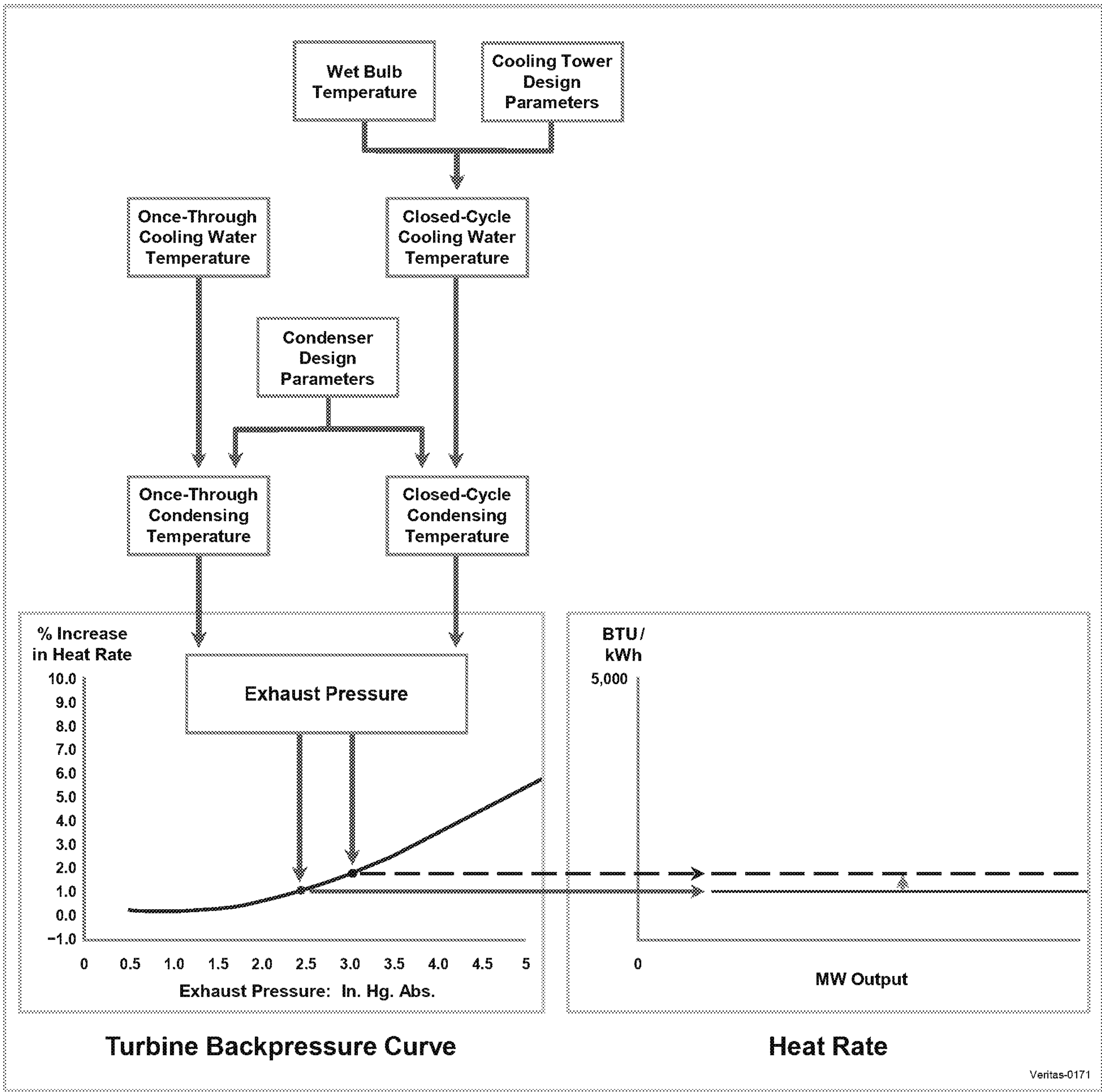

Figure 10: Technical Parameters and Ambient Conditions Underlie Efficiency Effects

Because this effect exhibits a good deal of nonlinear variability, we characterize it on an hourly basis.[13] Details for doing so (including equations) are presented in EPRI (2011b). The approach follows these general steps:

- Step 1—Collect and compile hourly ambient conditions data.
- Step 2—Calculate hourly approach temperatures.
- Step 3—Calculate cooling tower circulating temps.
- Step 4—Estimate the water temperature to heat rate curve
- Step 5—Determine efficiency impacts.

This results in an estimated hourly energy penalty effect that is specific to the atmospheric, water temperature and operating characteristics of the unit and tower and is relative to baseline conditions.

3.3.3 Step 1—Source Water and Wet Bulb Data

Information requirements for hourly ambient conditions include open-cycle source water temperatures and wet-bulb temperatures. Water temperature data is from the 2016 LEC Intake Study support data.

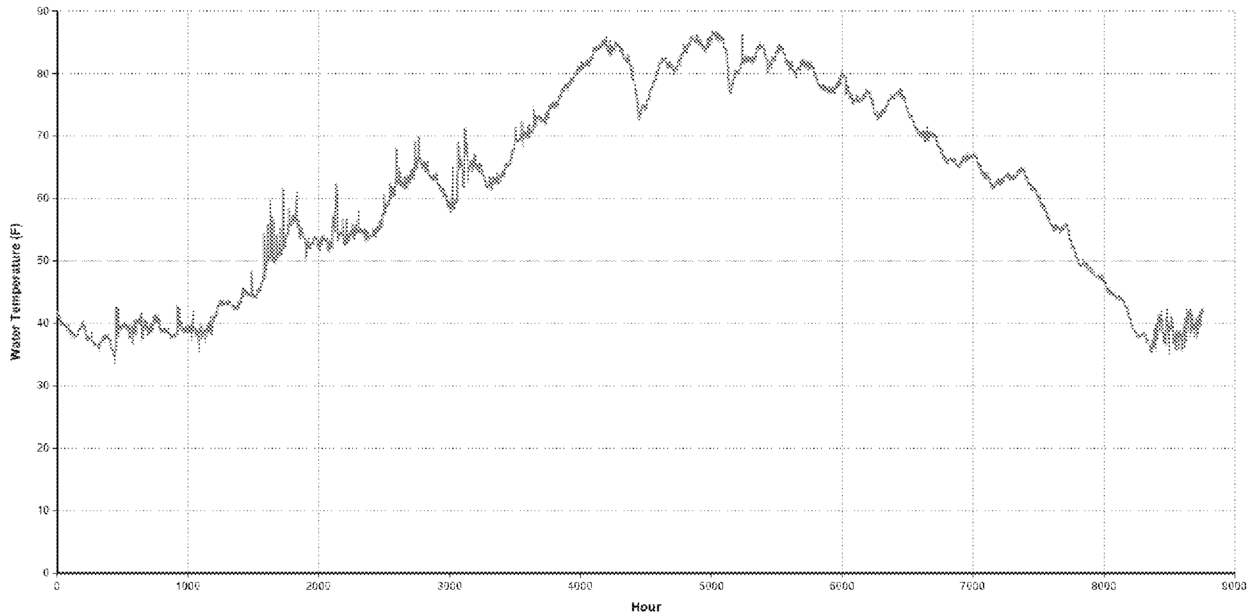

Figure 11: Hourly Once-Through Source Water Temperature Data

[13] Turbine backpressure curves are steepest and electricity prices are often highest when wet bulb temperatures are high.

Wet bulb data is available from the National Oceanic & Atmospheric Administration's (NOAA) National Centers for Environmental Information. Hourly wet bulb temperatures are desirable because they are more variable than water temperatures and because they can impact system load. The nearest publicly available readings are from the Spirit of St. Louis Airport in Chesterfield, Missouri. Hourly wet-bulb temperatures were developed by collapsing continuous wet-bulb data to hourly data and are presented in Figure 12.

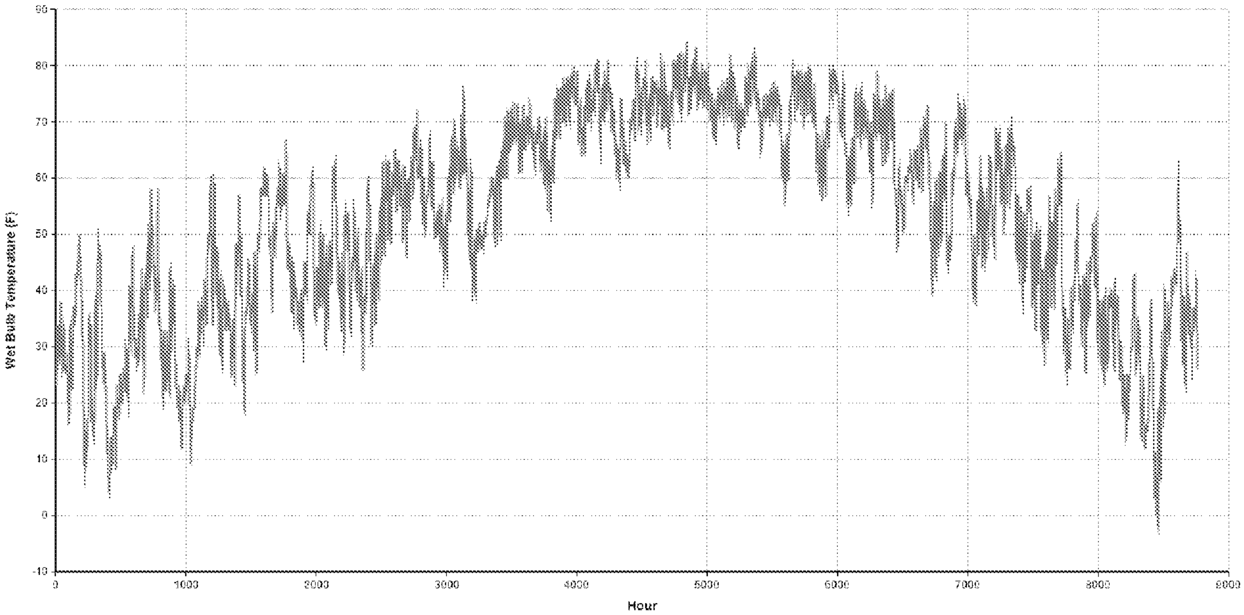

Figure 12: Hourly Wet Bulb Temperature Data for LEC

3.3.4 Step 2—Calculate Cooling Tower Approach Temperatures

For the cooling tower, the approach is calculated using the following equation (EPRI 2011b). Following the cooling tower design (Burns and McDonnell 2018) wet bulb and hourly approach are specified at 79.9 and 9 degrees, respectively.

$$\text{Approach} = 0.5 \times (CT_{Design\_Wet\_Bulb}) + (CT_{Design\_Approach}) - 0.5 \times (\text{Hourly\_Wet\_Bulb}) \quad \textbf{(2)}$$

Where

$CT_{Design\_Wet\_Bulb} = 79.9°F$

$CT_{Design\_Approach} = 9°F$

Cooling tower hourly approaches are depicted in Figure 13.

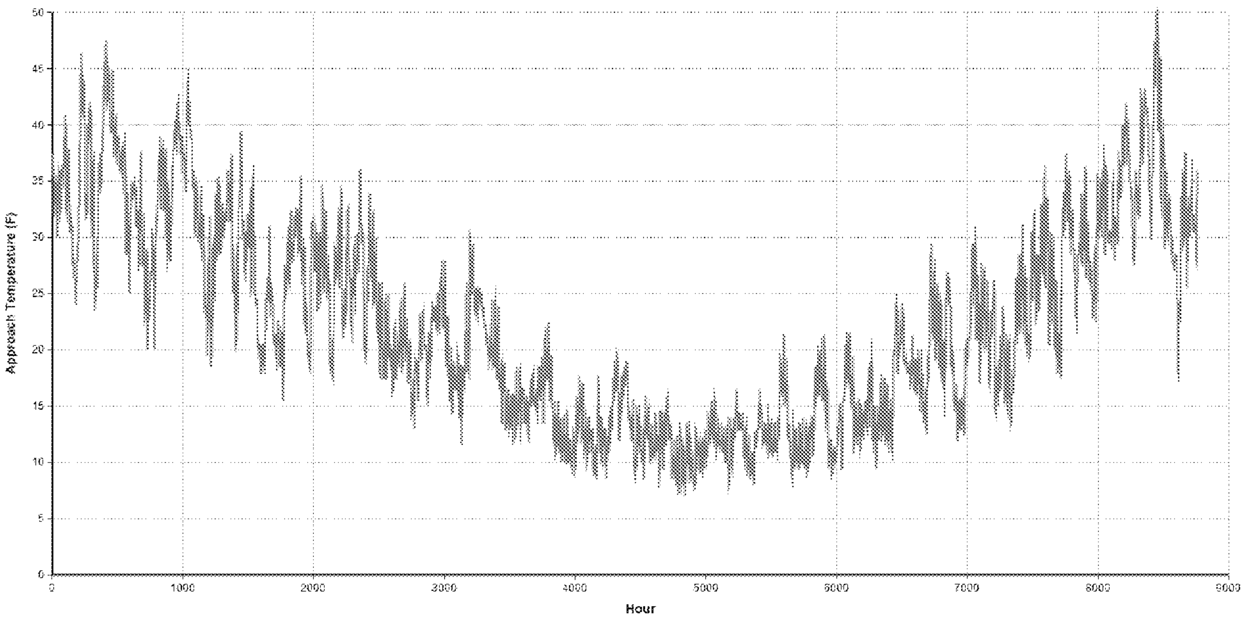

Figure 13: Hourly Approach Temperatures for LEC

3.3.5 Step 3—Calculate Cooling Tower Circulating Temperatures

Having information on cooling tower hourly approach and hourly wet bulb, circulating water temperatures for cooling towers are calculated following EPRI (2011b) as:

$$T^{h}_{cooling} = T^{h}_{wet\ bulb} + Approach^{h} \quad \textbf{(3)}$$

Where

$T^{h}_{Cooling}$ = Hourly cooling tower circulating water temperature

$T^{h}_{Wet\ Bulb}$ = Hourly wet bulb temperature

$Approach^{h}$ = Hourly cooling tower approach temperature

Figure 14 below depicts cooling water temperatures for once-through cooling (red curve) and closed-cycle cooling (blue curve).

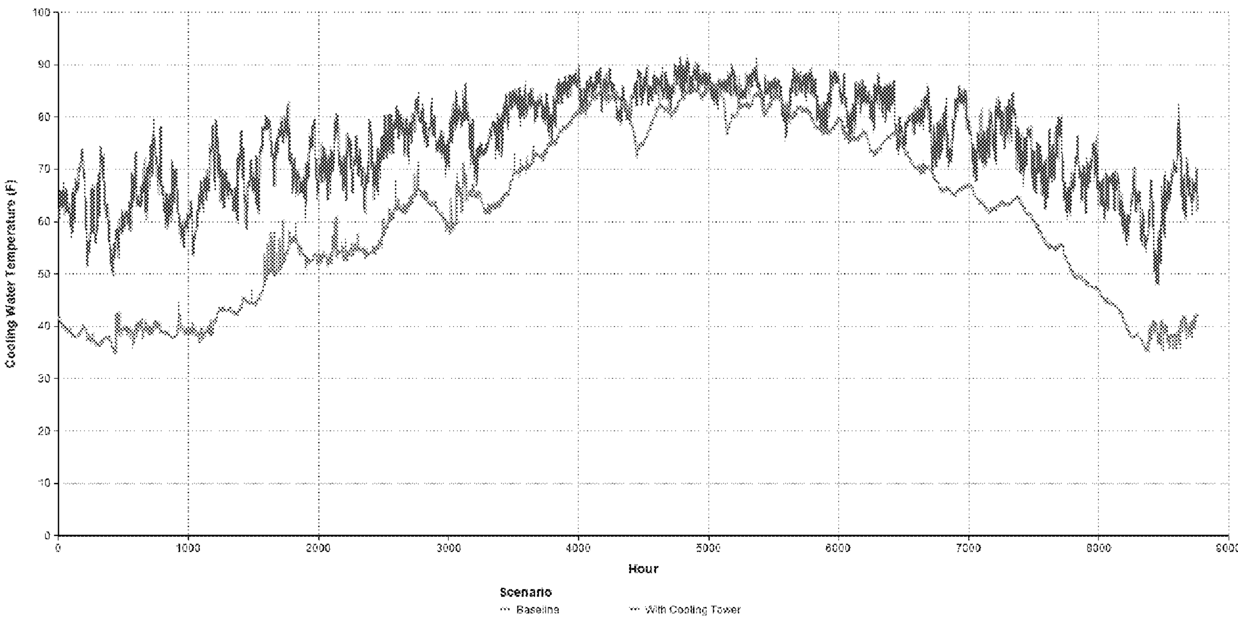

Figure 14: Cooling Water Temperatures for Once-Through and Closed-Cycle Cooling for LEC

3.3.6 Step 4— Estimate the Water Temperature to Heat Rate Curve

For fossil plants such as LEC, plant fuel input varies. Unit output and heat rate varies with each unit's operational state (e.g., startup versus running) and with cooling water temperatures and fuel input. Hourly output (in kw) and fuel input (in MMBtu) are available from the continuous emissions monitoring data (CEMS) collected by EPA's Air Markets Program[14] (U.S. EPA 2017). The relationship between cooling water temperatures and heat rate is identified by solving for hourly heat rate as kw/MMBtu and then regressing against water temperatures.[15] Other data employed account for the effects of ramping and output level on heat rate. This process results in an equation that relates water temperature and operational factors to heat rate. Tables 4, 5, and 6 list the variables used in deriving the relationships between water temperature and heat rate for LEC's Unit through 4.

[14] Data are located at http://ampd.epa.gov/ampd/.

[15] Data preparation procedures include certain validation and cleaning activities such as eliminating data that appears to come from when the plant is off, idling, or in start-up or shut-down mode.

Table 4
Regression Results for Estimating Backpressure Effects at LEC Units 1 and 2

Source	SS	dF	MS	Number of obs	=	7641
Model	16.9258714	4	4.23146785	F (4, 4069)	=	1057.07
Residual	30.5670251	7636	0.004003015	Prob > F	=	0.0000
Total	47.4928965	7640	0.006216348	R-squared	=	0.3564
				Adjusted R-squared	=	0.3561
				Root MSE	=	0.06327

Log HR	Coefficient	Standard Error	t	P>|t|	95% Conf. Interval	
Log W Temp	0.0043054	0.0025515	1.69	0.092	-0.0006962	0.0093071
RampUp	1.0410610	0.0208804	49.86	0.000	1.0001300	1.0819920
Rampdown	-0.0626116	0.0017942	-34.90	0.000	-0.0661288	-0.0590944
Log Pct Max	0.0108770	0.0029085	3.74	0.000	0.0051755	0.0165784
Constant	9.1320340	0.0103583	881.62	0.000	9.1117290	9.1523390

Table 5
Regression Results for Estimating Backpressure Effects at LEC Unit 3

Source	SS	dF	MS	Number of obs	=	7566
Model	67.6282965	4	16.9070741	F (4, 5928)	=	1958.39
Residual	65.2753697	7651	0.008633166	Prob > F	=	0.0000
Total	132.903666	7565	0.017568231	R-squared	=	0.5089
				Adjusted R-squared	=	0.5086
				Root MSE	=	0.09291

Log HR	Coefficient	Standard Error	t	P>|t|	95% Conf. Interval	
Log W Temp	0.0092131	0.0039759	2.32	0.021	0.0014191	0.0170071
RampUp	0.2537486	0.0057995	43.75	0.000	0.2423799	0.2651173
Rampdown	-0.0654969	0.0027670	-23.67	0.000	-0.0709209	-0.0600729
Log Pct Max	-0.1086577	0.0039874	-27.25	0.000	-0.1164741	-0.1008413
Constant	9.1269420	0.0159302	572.93	0.000	9.0957140	9.1581690

Table 6
Regression Results for Estimating Backpressure Effects at LEC Unit 4

Source	SS	dF	MS	Number of obs	=	6576
Model	39.8308278	4	9.95770696	F (4, 5928)	=	1352.18
Residual	48.3900045	6571	0.007364177	Prob > F	=	0.0000
Total	88.2208323	6575	0.013417617	R-squared	=	0.4515
				Adjusted R-squared	=	0.4512
				Root MSE	=	0.08581

Log HR	Coefficient	Standard Error	t	P>|t|	95% Conf. Interval	
Log W Temp	0.0139248	0.0035218	3.95	0.000	0.0070208	0.0208288
RampUp	0.9144191	0.0206425	44.30	0.000	0.8739532	0.9548850
Rampdown	-0.0841743	0.0023555	-35.73	0.000	-0.0887919	-0.0795566
Log Pct Max	-0.0594626	0.0041111	-14.46	0.000	-0.0675218	-0.0514035
Constant	9.0745090	0.0146217	620.62	0.000	9.0458460	9.1031730

Figure 15 graphically depicts the relationships between water temperature and heat rate.

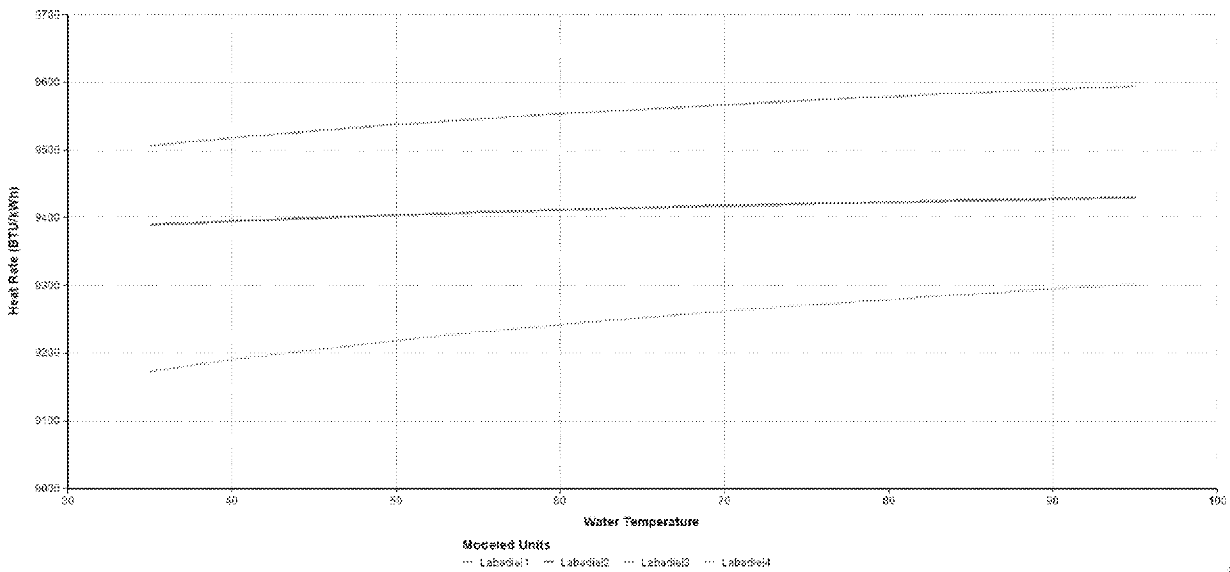

Figure 15: LEC Relationship between Water Temperature and Heat Rate

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3.3.7 Step 5—Determine Efficiency Impacts

The hourly cooling water temperatures and the equations that relate cooling-water temperature to output are used to identify heat rate under baseline and with cooling towers conditions. Figure 16 depicts heat rate for once-through and closed-cycle cooling for Unit 1.

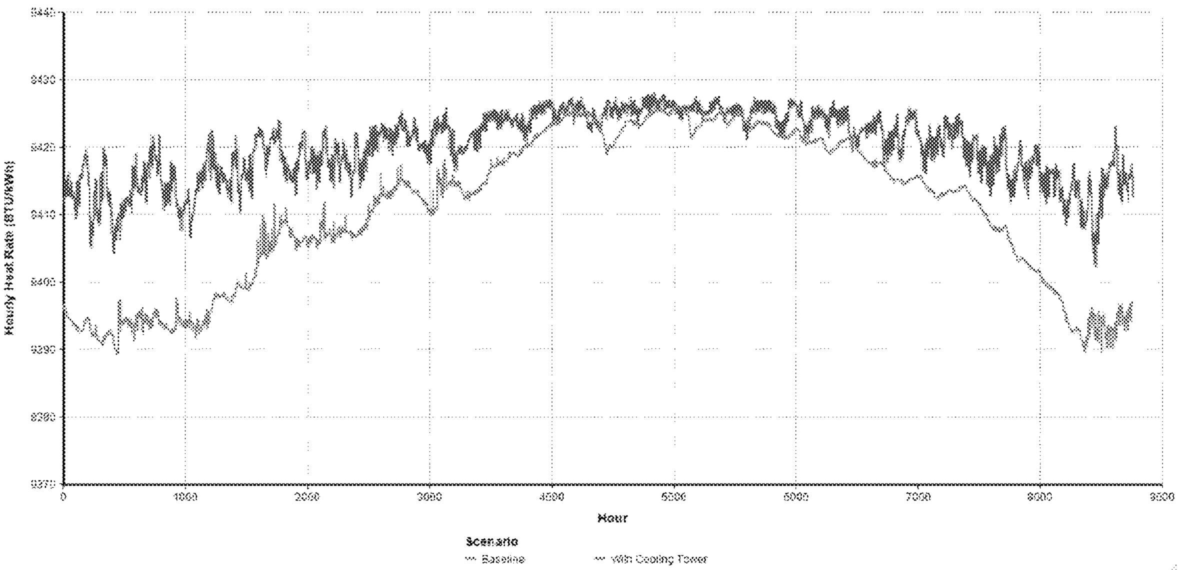

Figure 16: Hourly Heat Rate for LEC Unit 1

The red line represents baseline heat rate and the blue line represents the heat rate using closed-cycle cooling water. As the figures indicate, when using this warmer water, there is a loss in efficiency for every hour. Whereas once-through efficiencies relate to source water temperatures, closed-cycle efficiencies are related to atmospheric heat and humidity (that is, wet bulb temperatures). This leads to the more variable hourly effect evident in blue. The average annual loss in gross efficiency (i.e., not including capacity effects) for all hours is 0.10 percent, 0.10 percent, 0.22 percent, and 0.33 percent for Units 1, 2, 3, and 4, respectively. These vary hourly with maximum efficiency impacts being around 0.33 percent, 0.33 percent, 0.72 percent, and 1.08 percent for Units 1, 2, 3, and 4, respectively.

3.4 Specify Hourly Load

Because electricity production costs vary hourly and because important cooling tower effects that arise from wet bulb temperature vary hourly, modeling power system effects at the hourly level is useful. Modeled hourly load follows the shape of Ameren Missouri 2016 hourly load (Figure 17).

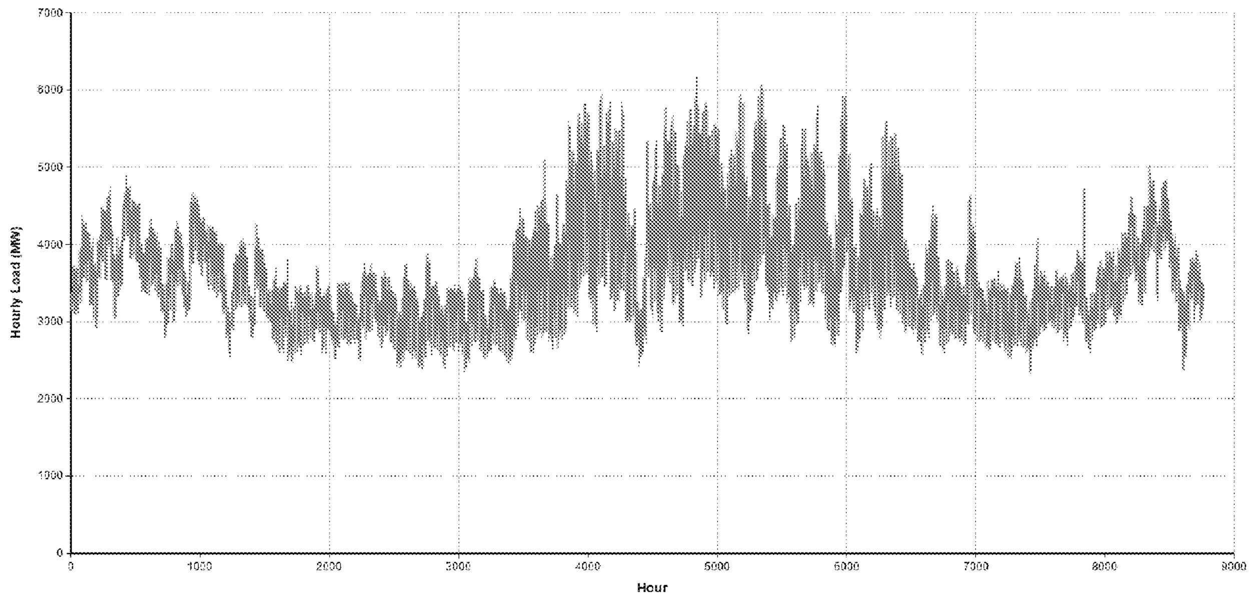

Figure 17: Ameren Missouri 2016 Modeled Hourly Load

3.5 Operate Model Under Baseline Conditions

Under Baseline conditions, operations are consistent with typical operating practices. The relationship between output and Btu consumption includes variation in cooling water temperature which lead to the hourly varying heat rate as depicted in Figure 18 for Unit 1.

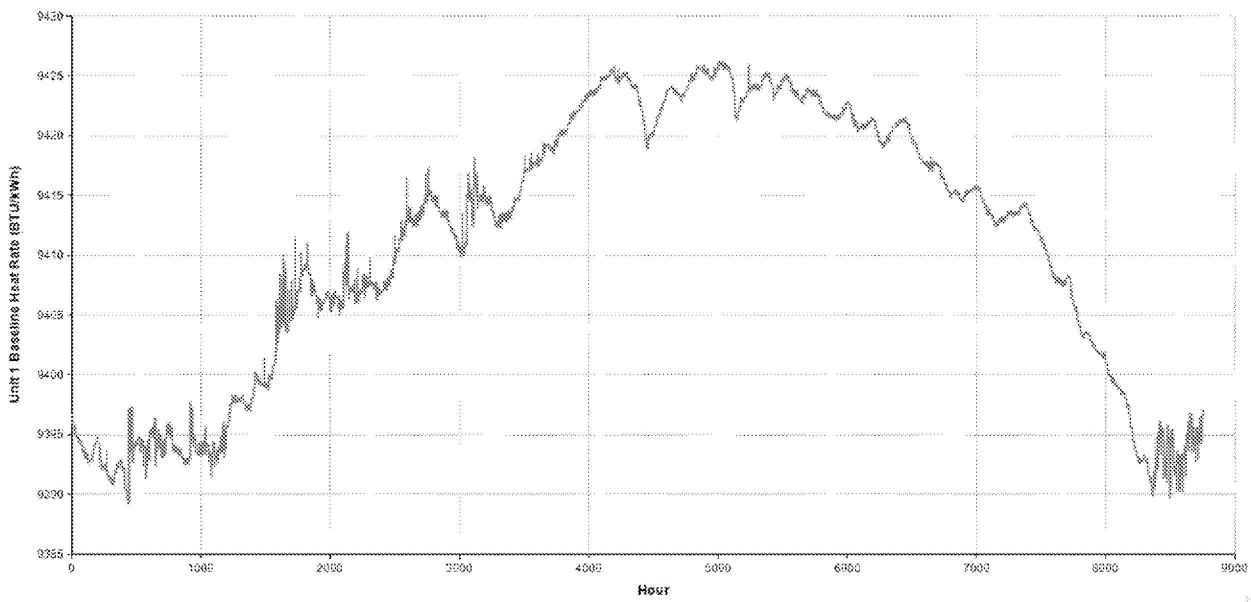

Figure 18: Baseline Heat Rate Unit 1

Operating the model under these Baseline conditions should produce results that are consistent with historical operations. The model is calibrated to reproduce LEC's 2016 generation as depicted for Unit 1 in Figure 19.

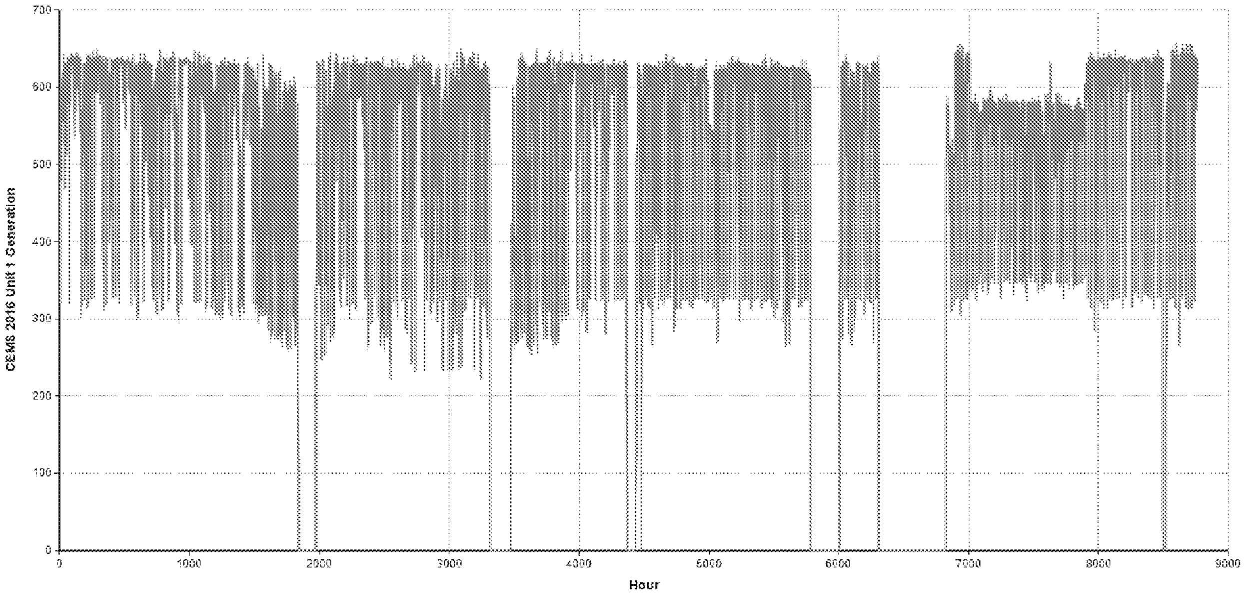

Figure 19: Model Calibrated Unit 1 Output

3.6 Create Scenarios Representing LEC's Conversion and Ongoing Operations

Counterfactual scenarios are created for five years. These reflect the physical implications of an outage for conversion and ongoing operations at LEC. For the conceptual level engineering design, the required outage time was not determined with precision. However, it is noted in the Burns & McDonnell (2018) evaluation that the outage is expected to be between 2 and 4 weeks. Unit 1 is expected to be complete within the first 48 months. Each successive unit is expected to take 16 months to install, finish associated balance of plant work, complete startup and complete outage tie-in (Burns and McDonnell 2018).

Post-conversion operations reflect net efficiency reductions from backpressure effects and auxiliary load. The cooling tower engineering evaluation specified 20 cells per unit. Together, the pump and fan loads require 28.90 MW (Burns and McDonnell 2018). In power system simulations, fans were specified as impacting system load consistent with the ratio of hourly generation to maximum capacity. Pumps are typically left on for condenser system maintenance purposes.

3.7 Run Simulations to Create Counterfactual Dispatch

With the counterfactual conditions set, the model is simulated to identify the counterfactual outcomes. These counterfactual outcomes are similar to those depicted in Figure 8. As Figure 8 indicates, additional units are dispatched to make up for lost net generation. Under a least cost dispatch approach this leads to equal or higher hourly costs. Figure 20 depicts the change in costs that occur when there is an outage for Unit 1 conversion followed by the operation of a cooling tower. Because there is no change prior to the Unit 1 outages, changes in costs do not begin until Hour 1417, when the outage begins.

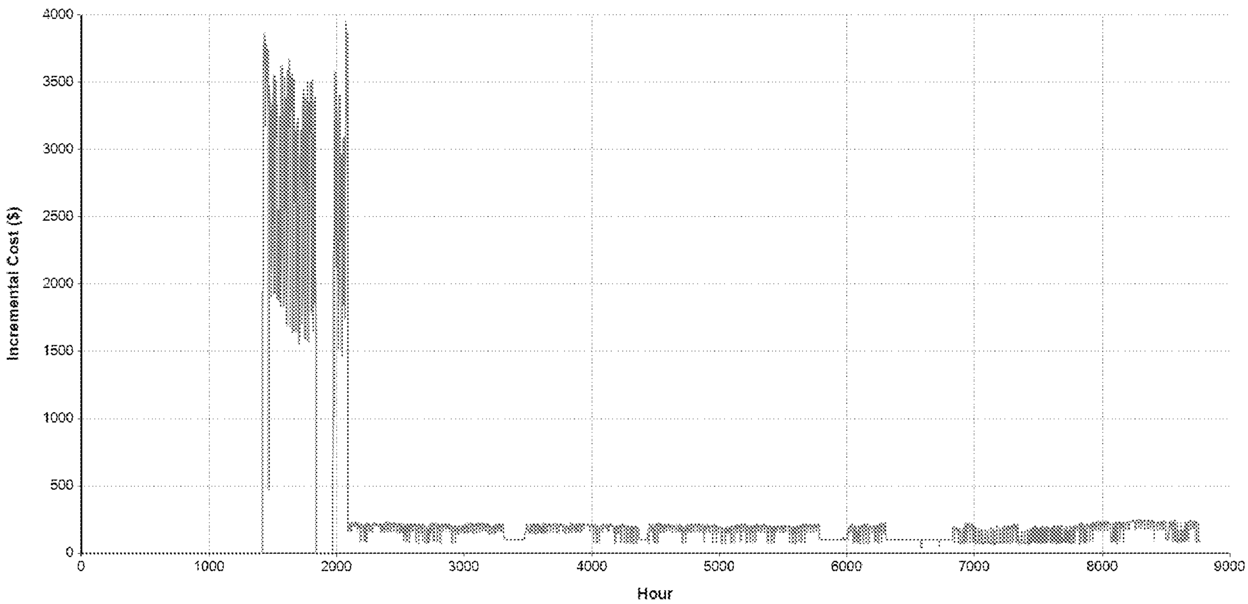

Figure 20: Incremental Hourly Costs in Unit 1's Closed-Cycle Cooling Conversion Year (Hour Zero is January 1st at 12am)

For the second outage year, Unit 1 would be running under counterfactual conditions (i.e., with-cooling-tower conversion). Figure 21 depicts the change in costs that occur when there is an outage for Unit 2 conversion followed by the operation of Unit 2's cooling tower. Changes in costs prior to Hour 1417, when Unit 2's outage begins, are the result of Unit 1's cooling tower running.

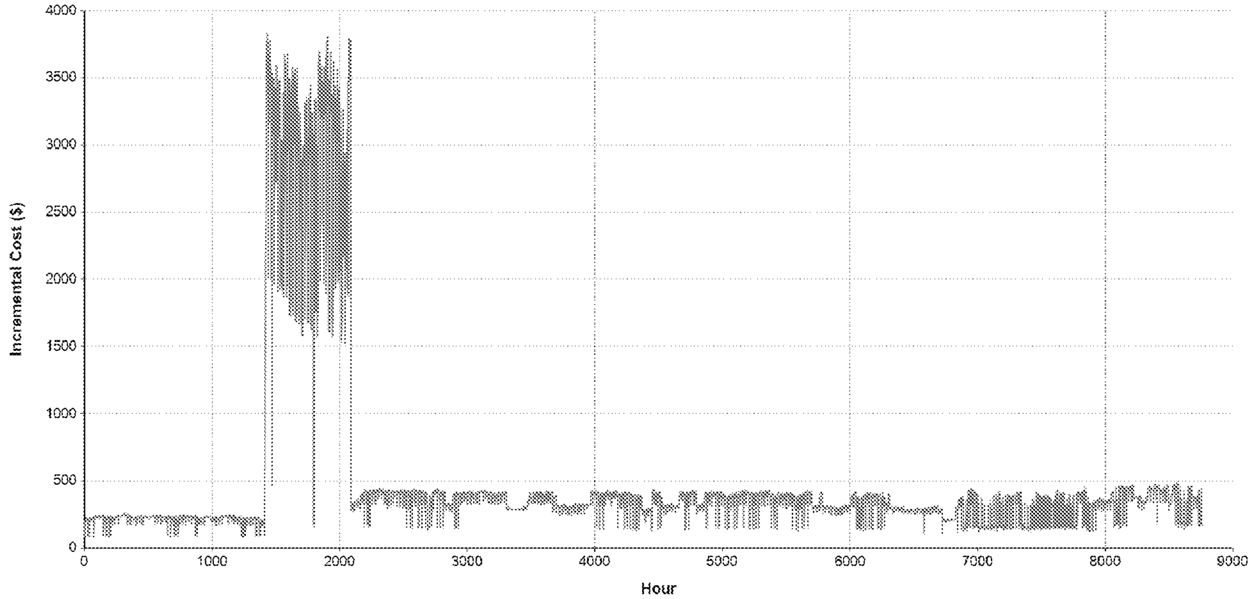

Figure 21: Incremental Hourly Costs in Unit 2's Closed-Cycle Cooling Conversion Year (Hour Zero is January 1st at 12am)

For the third outage year, Units 1 and 2 would be running under counterfactual conditions (i.e., with-cooling-tower conversion). Figure 22 depicts the change in costs that occur when there is an outage for Unit 3 conversion followed by the operation of Unit 3's cooling tower. Changes in costs prior to Hour 1417, when Unit 3's outage begins, are the result of Unit 1 and Unit 2's cooling towers running.

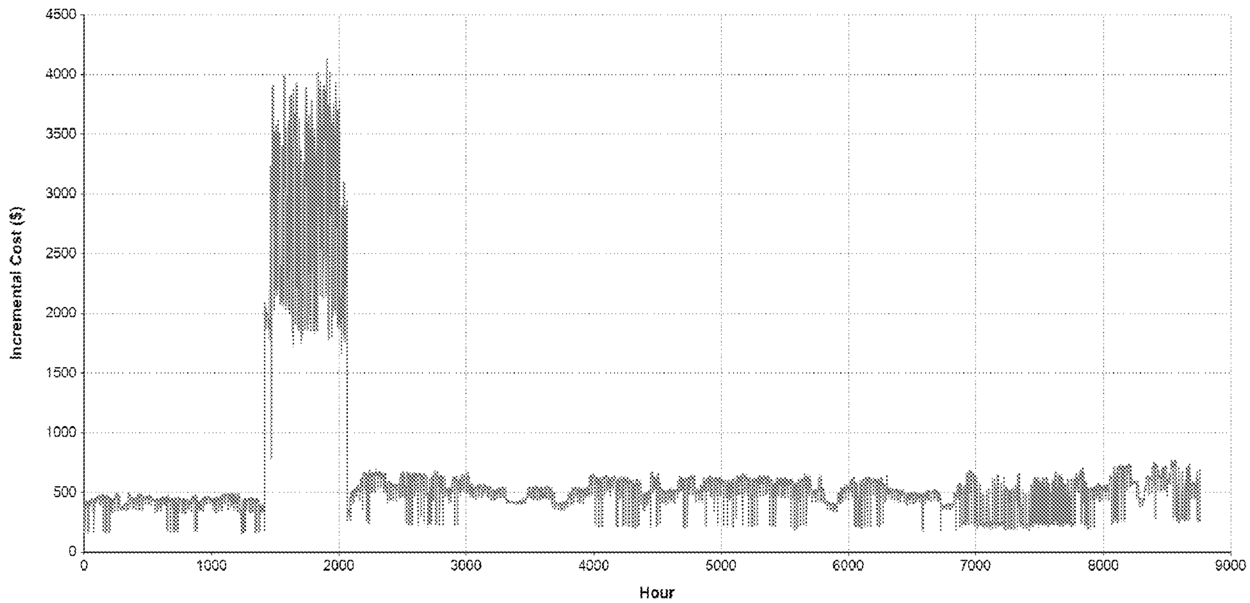

Figure 22: Incremental Hourly Costs in Unit 3's Closed-Cycle Cooling Conversion Year (Hour Zero is January 1st at 12am)

For the fourth outage year, Units 1 through 3 would be running under counterfactual conditions (i.e., with-cooling-tower conversion). Figure 23 depicts the change in costs that occur when there is an outage for Unit 4 conversion followed by the operation of Unit 4's cooling tower. Changes in costs prior to Hour 1417, when Unit 4's outage begins, are the result of Unit 1, Unit 2, and Unit 3's cooling towers running.

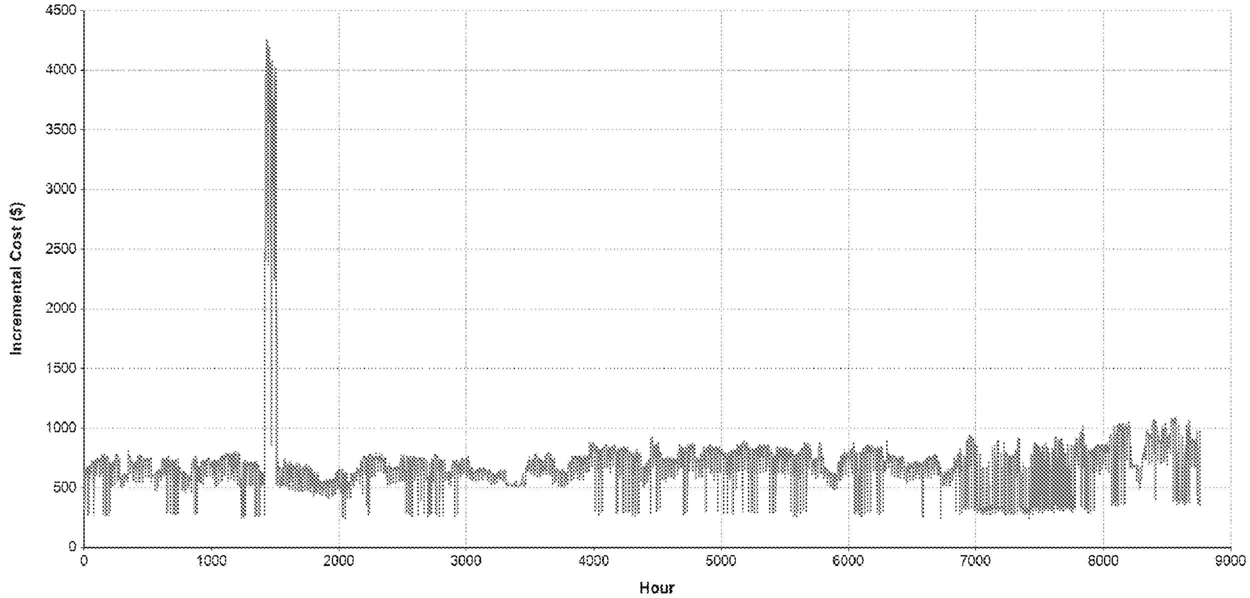

Figure 23: Incremental Hourly Costs in Unit 4's Closed-Cycle Cooling Conversion Year (Hour Zero is January 1st at 12am)

As the units come back online, additional load is incurred because of auxiliary load and backpressure effects. Total power system costs for the first conversion year are \$2.589M. Power system costs for the second conversion year are \$4.392M. Power system costs for the third conversion year are \$5.742M. Power system costs for the fourth conversion year are \$6.077M.

A typical year with cooling tower operation has costs like those of the post-conversion period depicted in Figure 23. However, these effects occur over the entire year as depicted in Figure 24.

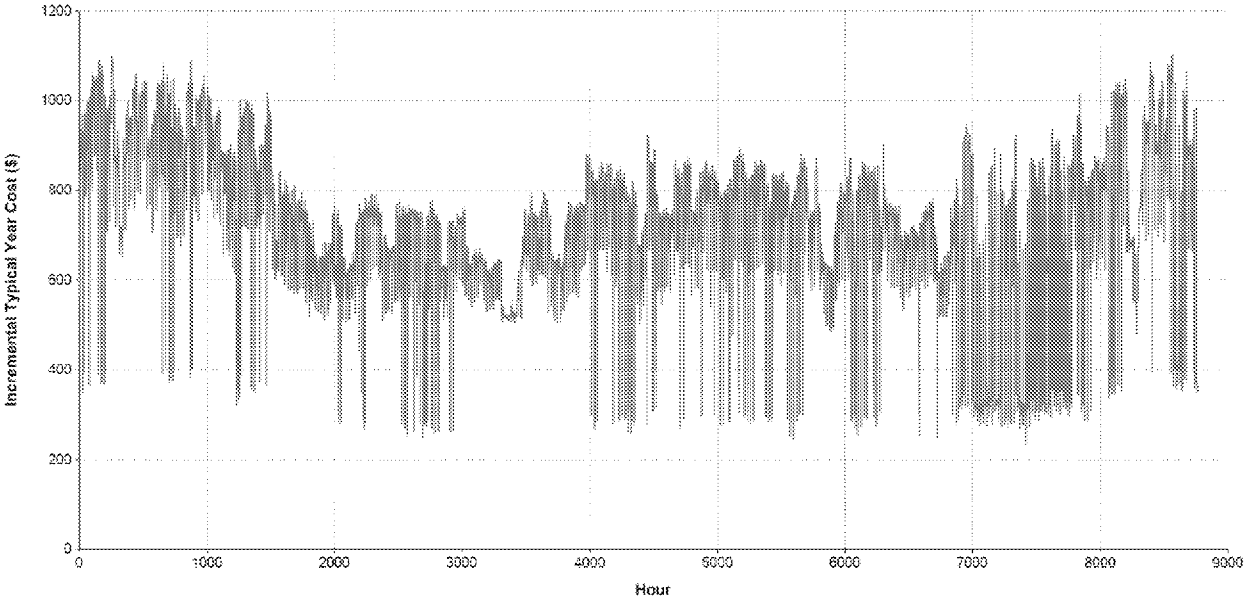

Figure 24: Incremental Hourly Costs in Typical Year after Conversion to Closed-Cycle Cooling

As Figure 24 indicates, ongoing costs reach their maximum at about $1,100 per hour. Because of continual pump operation, costs occur in all hours with a minimum of approximately $250. Power system costs for the typical ongoing year total $6.221M.

Similar calculations were conducted for auxiliary loads 2.0mm dual-flow fine mesh screens and 0.5mm fine mesh screens. Power requirements for the 2.0mm dual-flow fine mesh screens is expected to be similar to the power requirements of the anticipated future minimum baseline operation condition which is impingement compliance with TWSs that are continuously rotating and washing. Power requirements of the 0.5mm fine mesh screens is expected to be 5,900 MW annually using a capacity factor of 75 percent. Table 7 summarizes the incremental power system costs by year for each technology. Tables 8 through 11 present incremental increases in fuel consumption and emissions for closed-cycle cooling and 0.5mm fine mesh screens.

Table 7
Incremental Power System Costs by Technology

Technology	Conversion Year 1	Conversion Year 2	Conversion Year 3	Conversion Year 4	Ongoing Year
Closed-Cycle Cooling	$2.589M	$4.392M	$5.742M	$6.077M	$6.22M
2.0mm Dual-Flow FMS	$0	—	—	—	$0
0.5mm FMS	$0.117M	—	—	—	$0.156M

Table 8
Net Fuel Consumption and Costs from Closed-Cycle Cooling

Metric	Conversion Year 1	Conversion Year 2	Conversion Year 3	Conversion Year 4	Ongoing Year
MMBtu	0.5M	1.09M	1.69M	2.92M	2.42M
$	$2.589M	$4.392M	$5.742M	$6.077M	$6.221M

Table 9
Net Air Emissions from Closed-Cycle Cooling

Pollutant	Conversion Year 1	Conversion Year 2	Conversion Year 3	Conversion Year 4	Ongoing Year
Carbon Dioxide (CO2) tons	47.51K	98.79K	154.0K	208.3K	221.6K
Sulfur Dioxide (SO2) tons	0.23K	0.33K	0.43K	0.48K	0.49K
Nitrogen Oxide (NOX) tons	0.03K	0.08K	0.11K	0.119K	0.124K
Particulate Matter (PM) tons	1.99K	4.14K	6.46K	8.73K	9.29K

Table 10
Net Fuel Consumption and Costs from 0.5mm Fine Mesh Screens

Metric	Conversion Years	Ongoing Year
MMBtu	46.1K	60.4K
$	$0.117M	$0.156M

Table 11
Net Air Emissions from 0.5mm Fine Mesh Screens

Pollutant	Conversion Years	Ongoing Year
Carbon Dioxide (CO2) tons	4.15K	5.58K
Sulfur Dioxide (SO2) tons	8.73	12.30
Nitrogen Oxide (NOX) tons	2.52	3.16
Particulate Matter (PM) tons	173.9	223.9

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Appendix 11 A
40 CFR 122.21(r)(11) – Benefits Valuation Study

Methods Used to Estimate Biological Efficacy of Fine-Mesh Screening Technology at the LEC

In this report, fine-mesh screens refer to fine-mesh traveling water screens. This technology reduces entrainment by preventing smaller aquatic organisms from entering the cooling water intake structure. With fine-mesh traveling screens, the excluded organisms are retained on the screen and then transported by a screen wash system back to the source waterbody. This handling imparts additional stress, injury and scale loss that could lead to mortality of the excluded organisms. Therefore, to properly measure the potential biological benefits of fine mesh traveling water screens, the mortality of the eggs, larvae, and early juveniles that would be retained on the screens must also be considered. This mortality is species-specific and dependent upon their biology (life stage, relative hardiness, etc.) as well as the screen operating characteristics (rotation speed, spraywash pressure, etc.) at this facility.

This attachment describes the methods and estimates of exclusion for each of the two mesh sizes evaluated at the LEC; 0.5 mm and 2.0 mm for each of the Target Taxa. In addition, estimates of subsequent retention mortality for each of the Target Taxa are provided for fine-mesh traveling water screens alternatives.

Retention

The retention rate of entrained larvae and entrainable juveniles for each of the five Target Taxa selected for the LEC was estimated based on site-specific measurements collected as part of a Entrainment Characterization Study. Retention was estimated under the assumption that the maximum cross-sectional diameter of the organism must be greater than the mesh diagonal if it is to be fully retained as proposed by Smith et al. (1968). For eggs, the cross-sectional diameter is simply the mean diameter of the egg, however since larval fish are soft bodied and can be compressed, the deepest non-compressible portion of the body is the head capsule. Hence, the head capsule depth (HCD) was used to predict exclusion.

Larval and entrainable juvenile length and HCD measurements from an entrainment monitoring program conducted at the Sequoyah Nuclear Station in 2015 and 2016[1] were used to estimate exclusion for freshwater drum and gizzard shad. For the other two Target Species, larval and entrainable juvenile length and HCD measurements were obtained from the studies conducted and reported in EPRI (2010). These data were used to develop a polynomial relationship between the two measurements for each of the Target Taxa:

$$HCD = aL^3 + bL^2 + cL + d$$

where:

L = Total length of larvae.

Estimate model parameters for each of the Target Taxa are:

Target Species	Surrogate	n[a]	a	b	c	d	δ^2
Channel catfish	Channel catfish	5	0.19748	-0.65624	0	0	0.03923
Freshwater Drum	Drum family	314	0.29148	-0.08951	0.03917	0.00000	0.01118
Gizzard Shad	Herring family	345	0.69882	-0.12447	0.01395	-0.00014	0.07854
Minnows	Emerald shiner	6	0.13613	-0.11535	0	0	0.00182

[a]Number of individual measurements.

[1] Data provided courtesy of the Tennessee Valley Authority (TVA). Study collected all of the species groups used in this assessment. See TVA (2017) for details on study.

Using these species-specific polynomial models, the mean HCD (μ) and associated variance (δ^2) about this estimate can be calculated for any length. The individual measurements of length and HCD along with the polynomial regression models for each of the four Target Taxa are provided in the top panel of Figures A-1 through A-4.

Using the estimates of mean and variance of HCD associated with each length as described above, probabilities of exclusion [Pr(X $\leq$ x)] were derived for each Target Taxa and screen mesh dimension by integrating estimated HCDs and the associated standard deviations under a normal curve:

$$\Pr(X \leq x) = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{x} e^{-\left(\frac{(\ln(x)-\mu)^2}{2\sigma^2}\right)}$$

where:

x = minimum mesh dimension;
μ = predicted mean natural log (ln) (HCD); and,
σ^2 = variance of predicted ln (HCD)

Estimates of retention for each of two screen mesh dimensions and for each Target Taxa are provided in bottom panel of Figures D-1 through D-4.

When using a morphometric approach to estimating fine-mesh exclusion such as above, however, it should be noted that other factors such as water velocity, headloss, orientation of the larvae at the time of contact with the mesh, and consistency of mesh opening sizes can impact the accuracy of these models in predicting exclusion. Results from EPRI-sponsored laboratory studies (EPRI 2010) indicate that organisms physically able to pass through screen mesh do not always become entrained. Such organisms are sometimes collected in the fish return buckets or become impinged on the mesh due to a lateral orientation to the flow direction and body lengths that span several screening filaments. In these cases, the morphometric approach would underestimate retention. On the contrary, gaps between traveling water screen gaskets, gaps in side seals, or carryover issues could result in entraining organisms which were theoretically too large to pass through the mesh.

Fine mesh screen exclusion rates for eggs of the Target Taxa were based on egg diameters assuming a 10 percent compression. Egg diameters were obtained from Auer (1982) and Wang and Kernehan (1979). The resulting best professional estimates of percent exclusion by screen mesh opening are as follows:

Target Species[a]	Screen Opening		
	0.5 mm	1.0 mm	2.0 mm
Minnows	100	100	99
Freshwater Drum	100	90	0
Gizzard Shad	99	15	0
Channel catfish	-	-	-

[a] No catfish eggs entrained.

Retention Survival

Evaluation of potential retention survival began with a review of studies on fine-mesh traveling water screen survival for other sites with modified traveling water screens or other evaluations (e.g., laboratory and pilot-scale studies). For the Target Taxa entrained at the LEC, a number of studies on fine mesh retention survival for larvae and entrainable juveniles were identified (Table D-1). In addition, Bruzek and Mahadevan (1986) reported an initial survival rate of 63 percent for freshwater drum.

Based on this information, estimates of the survival rates of each life stage of each of the Target Taxa using BPJ were developed and these values are listed in Table D-2.

Table 11 A-1 Available information on impingement survival for each Target Species by life stage.

Target Species	Surrogate	Life Stage	Size Range (mm)	n	Survival Range	Reference
Minnows	None	Larval	NR	186	33.3 - 96.2	Beak Consultants 1987 & 1988
	Cyprinidae	Juvenile	36-113*	27,406	49.3 - 98.2	Beak Consultants 2000a, 2000b; Lindsay 1991; LMS 1991; Normandeau 1995; EPRI 2006*
Freshwater Drum	None	Egg	1.15-2.0	51,202	-	Bruzek & Mahadevan 1986
		Larval	3.3-14.3	24581	0.4 - 4.8	Kuhl & Mueller 1988
		Juvenile	41-104	1,189	99.5 - 100.0	EPRI 2006
Gizzard Shad	Herring Family	Larval	5.5-21.7	2922	0 - 1.0	Kuhl & Mueller 1988
		Juvenile	38-461	8,828	0.0 - 100.0	Beak Consultants 2000a, 2000b; LMS 1991; Normandeau 1995
Channel catfish	None	Larval	9.7-23.0	17,220	18.0-85.0	EPRI 2010
	Ictalurus spp.	Juvenile	NR	2,247	0.0-100.0	EPRI 2013

NR = Not Reported

Table 11 A-2 Best professional judgement impingement survival for each Target Species by life stage used to calculate entrainment losses at the LEC.

Target Species	Life Stage	BPJ Survival (Percent)
Minnows	Egg	50.0 [a]
	Larval	62.4
	Juvenile	78.6
Freshwater Drum	Egg	63.0
	Larval	3.0
	Juvenile	99.5
Gizzard Shad	Egg	50.0 [a]
	Larval	1.0
	Juvenile	51.6
Channel catfish	Larval	50.0 [a]
	Juvenile	81.4

[a] No information. Assumed value based on studies conducted on other species.

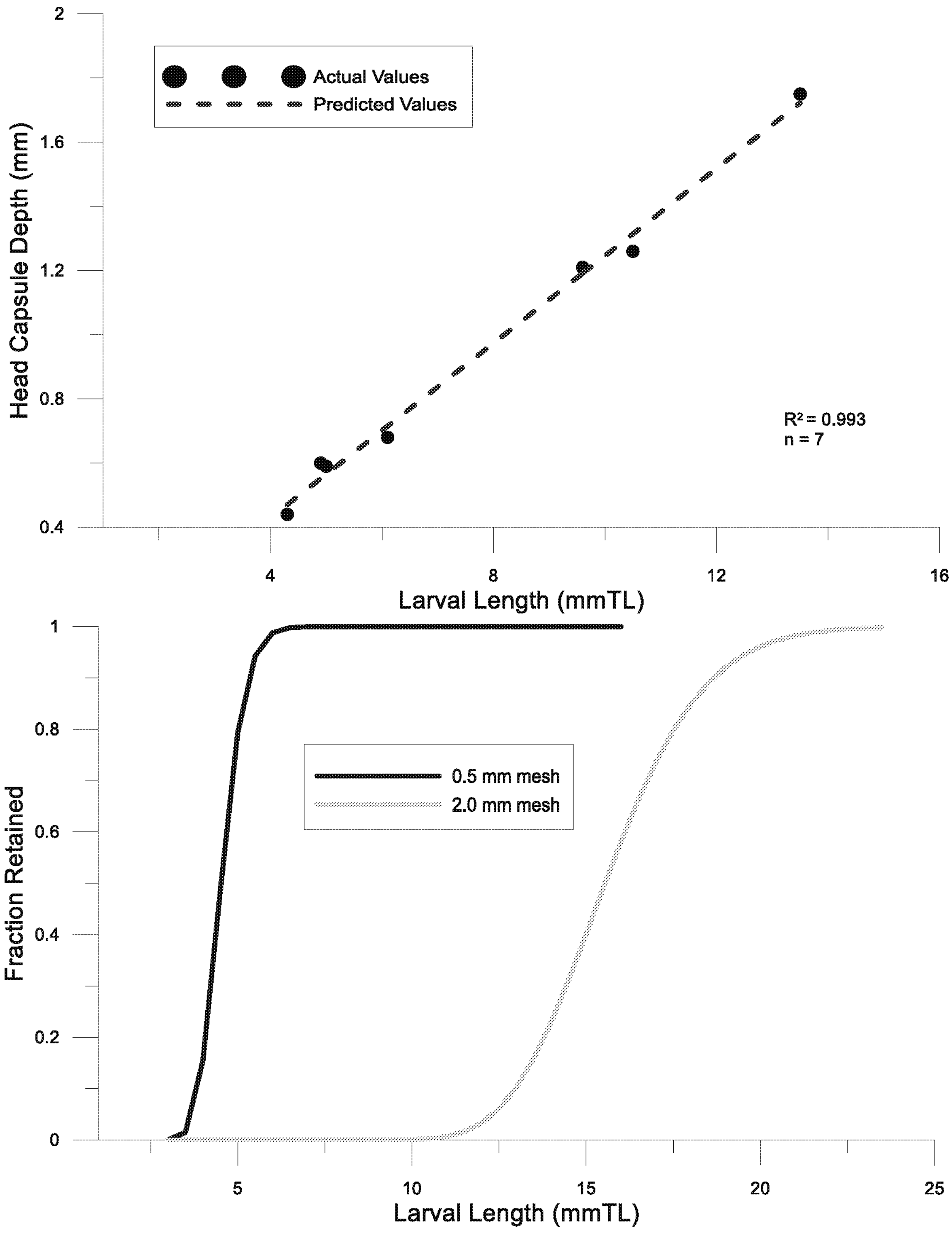

Figure 11 A-1 Head capsule depth (top) and predicted screen retention (bottom) as a function of the minnow larval and early juvenile length based on the results of studies reported in EPRI (2013).

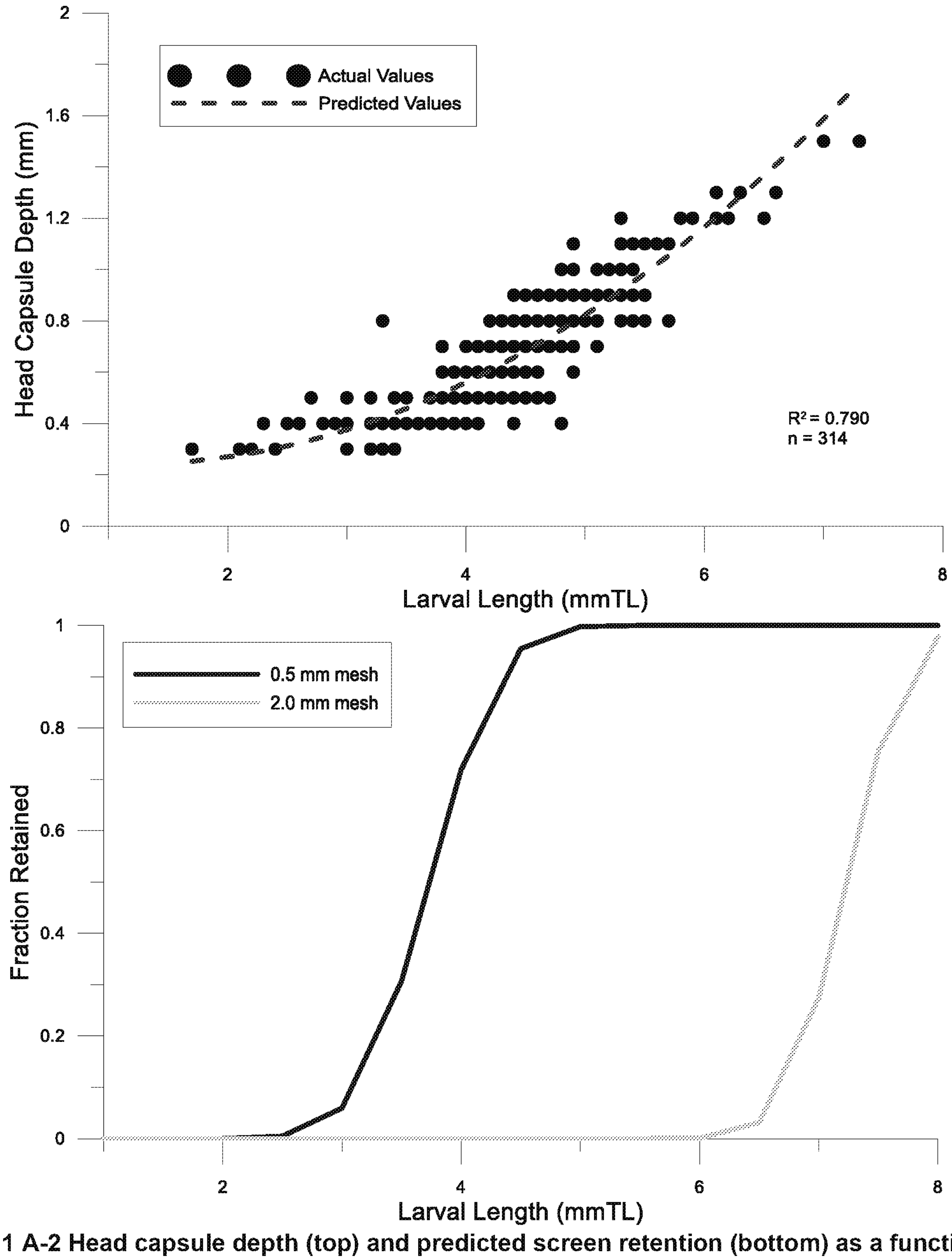

Figure 11 A-2 Head capsule depth (top) and predicted screen retention (bottom) as a function of the drum family (*Sciaenidae*) larval and early juvenile length based on the results of entrainment monitoring at the Sequoyah Nuclear Station in 2015 and 2016.

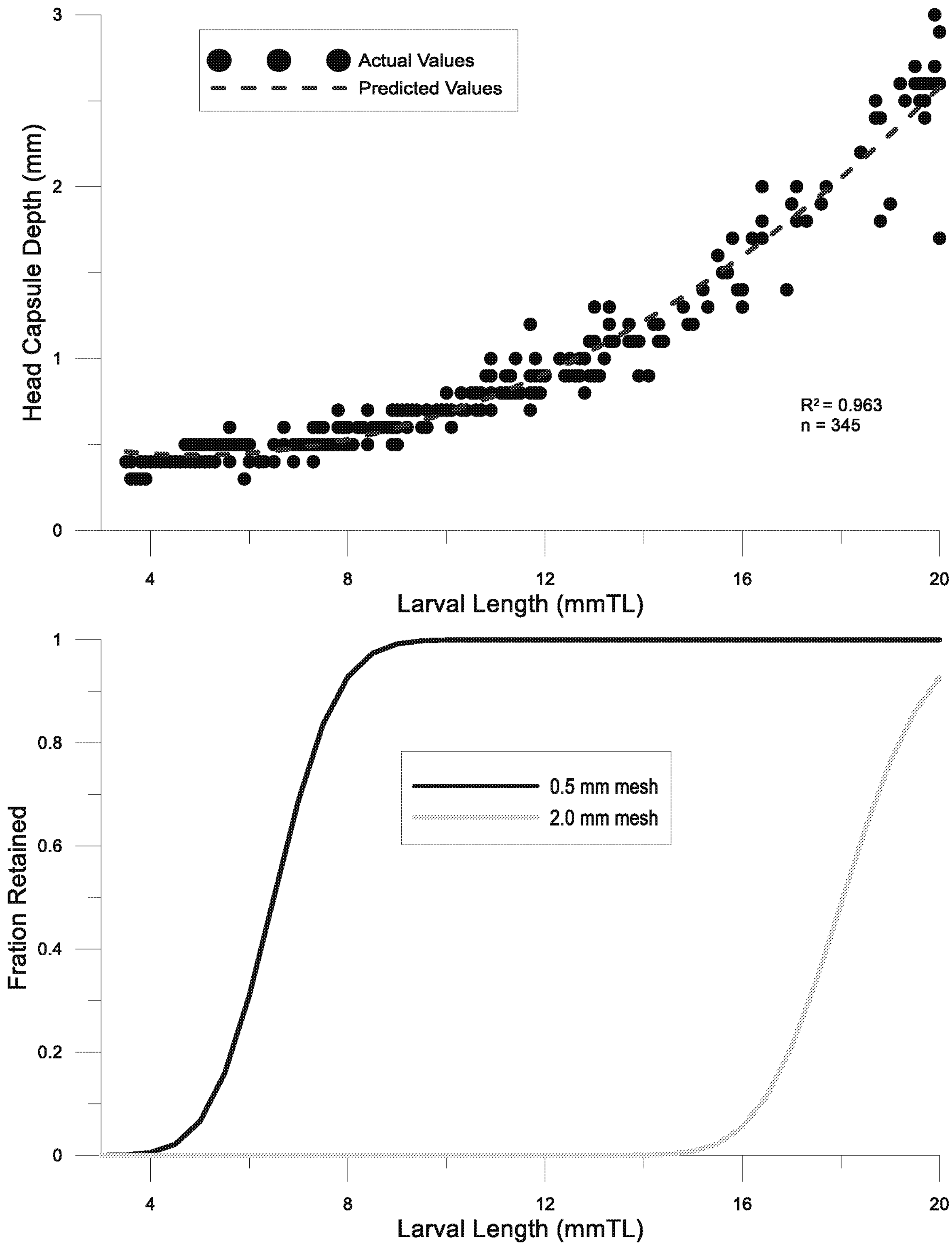

Figure 11 A-3 Head capsule depth (top) and predicted screen retention (bottom) as a function of length for the herring family (*Clupeidae*) larval and early juvenile length based on the results of entrainment monitoring at the Sequoyah Nuclear Station in 2015 and 2016.

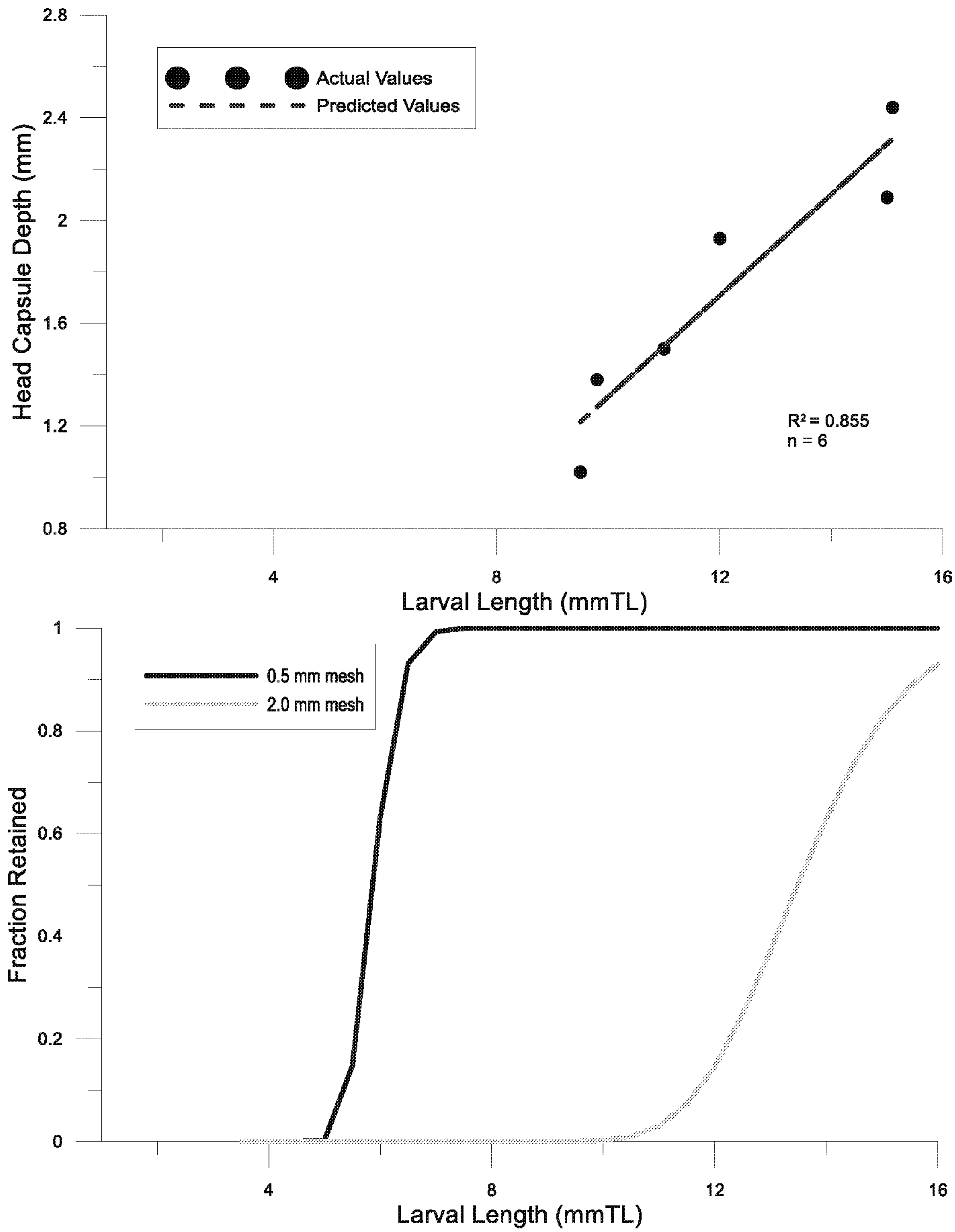

Figure 11 A-4 Head capsule depth (top) and predicted screen retention (bottom) as a function of length for the channel catfish larval and early juvenile length based on the results of studies reported in EPRI (2013).

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Appendix 11 B

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Target Species Life History Parameters

Table 11 B-1 Life history parameters for channel catfish used to calculate equivalent losses[a].

Age/Stage	Duration	Natural Mortality Rate (M)	Fishing Mortality Rate (F)	Fishing Vulnerability	Weight at Beginning (g)	Fraction Female	Fraction Mature	Annual Egg Production per Female
Egg	8	0.0687[b]	0.0000	0.00	0.0017			
YSL	9	0.0687[b]	0.0000	0.00	0.0017			
PYSL	14	0.0687[b]	0.0000	0.00	0.0039[c]			
Ent. Juv	40	0.01163[b]	0.0000	0.00	0.0460			
Age 0	294	0.01163[b]	0.0000	0.00	0.0678[c]			
Age 1	365	0.0008[c]	0.0008[c]	0.00	1.3	0.50	0.00	
Age 2	365	0.0008[c]	0.0008[c]	0.00	20.3	0.50	0.00	
Age 3	365	0.0008[c]	0.0008[c]	0.00	77.9	0.50	0.00	
Age 4	365	0.0008[c]	0.0008[c]	1.00[d]	195.6	0.50	1.00	609
Age 5	365	0.0008[c]	0.0008[c]	1.00[d]	399.5	0.50	1.00	1,243
Age 6	365	0.0008[c]	0.0008[c]	1.00[d]	701.3	0.50	1.00	2,183
Age 7	365	0.0008[c]	0.0008[c]	1.00[d]	1,186.0	0.50	1.00	3,691
Age 8	365	0.0008[c]	0.0008[c]	1.00[d]	1,697.2	0.50	1.00	5,283
Age 9	365	0.0008[c]	0.0008[c]	1.00[d]	2,724.6	0.50	1.00	8,480
Age 10	365	0.0008[c]	0.0008[c]	1.00[d]	3,968.3	0.50	1.00	12,351
Age 11	365	0.0008[c]	0.0008[c]	1.00[d]	3,595.1	0.50	1.00	11,190
Age 12	365	0.0008[c]	0.0008[c]	1.00[d]	4,773.6	0.50	1.00	14,858

[a] Unless otherwise noted, all values from EPRI (2012), Table 5-76 and 5-78 for channel catfish, Mississippi River.
[b] Adjusted to stable population as described in Attachment C.
[c] Assumed species fully exploited by commercial and recreational fishermen (m = z/2; f= z/2).
[c] These stage weights determined by interpolation assuming a constant instantaneous growth rate.
[d] Based on information provided in Graham and DeiSanti (1999).

Table 11 B-2 Life history parameters for emerald shiner used to calculate equivalent losses[a]

Age/Stage	Duration	Natural Mortality Rate (M)	Fishing Mortality Rate (F)	Fishing Vulnerability	Weight at Beginning (g)	Fraction Female	Fraction Mature	Annual Egg Production per Female
Egg	7	0.0608[b]	0.0000	0.00	0.0018			
YSL	19	0.0608[b]	0.0000	0.00	0.0030[c]			
PYSL	19	0.0608[b]	0.0000	0.00	0.0118[c]			
Ent. Juv	40	0.0127[b]	0.0000	0.00	0.0465			
Age 0	280	0.0127[b]	0.0000	0.00	0.0586[c]			
Age 1	365	0.0049	0.0000	0.00	2.4057	0.50	1.00	1,500
Age 2	365	0.0049	0.0000	0.00	5.1951	0.50	1.00	1,500
Age 3	365	0.0049	0.0000	0.00	6.7522	0.50	1.00	1,500
Age 4	365	0.0049	0.0000	0.00	7.4775	0.50	1.00	1,500

[a] Unless otherwise noted, all values from EPRI (2012), Table 5-92 and 5-93, emerald shiner.
[b] Adjusted to stable population as described in Attachment C.
[c] These stage weights determined by interpolation assuming a constant instantaneous growth rate.

Table 11 B-3 Life history parameters for freshwater drum used to calculate equivalent losses[a].

Age/Stage	Duration	Natural Mortality Rate (M)	Fishing Mortality Rate (F)	Fishing Vulnerability	Weight at Beginning (g)	Fraction Female	Fraction Mature	Annual Egg Production per Female
Egg	5	0.2136[b]	0.0000	0.00	0.00006	0.50	0.00	
YSL	20	0.2136[b]	0.0000	0.00	0.00006	0.50	0.00	
PYSL	20	0.2136[b]	0.0000	0.00	0.00188[c]	0.50	0.00	
Ent. Juv	40	0.0087[b]	0.0000	0.00	0.06000	0.50	0.00	
Age 0	280	0.0087[b]	0.0000	0.00	0.14581[c]	0.50	0.00	
Age 1	365	0.00033	0.0000	0.00	73	0.50	0.00	
Age 2	365	0.00033	0.0000	0.00	114	0.50	0.00	
Age 3	365	0.00033	0.0000	0.00	164	0.50	0.00	
Age 4	365	0.00033	0.0000	0.00	223	0.50	0.50	21,764
Age 5	365	0.00033	0.0000	0.00	290	0.50	1	28,271
Age 6	365	0.00033	0.0000	0.00	363	0.50	1	35,456
Age 7	365	0.00033	0.0000	0.00	443	0.50	1	43,221
Age 8	365	0.00025[d]	0.00008[d]	1.00[e]	527	0.50	1	51,467
Age 9	365	0.00025[d]	0.00008[d]	1.00[e]	616	0.50	1	60,096
Age 10	365	0.00025[d]	0.00008[d]	1.00[e]	707	0.50	1	69,016
Age 11	365	0.00025[d]	0.00008[d]	1.00[e]	801	0.50	1	78,139
Age 12	365	0.00025[d]	0.00008[d]	1.00[e]	896	0.50	1	87,388
Age 13	365	0.00025[d]	0.00008[d]	1.00[e]	991	0.50	1	96,689
Age 14	365	0.00025[d]	0.00008[d]	1.00[e]	1086	0.50	1	105,980
Age 15	365	0.00025[d]	0.00008[d]	1.00[e]	1181	0.50	1	115,205
Age 16	365	0.00025[d]	0.00008[d]	1.00[e]	1274	0.50	1	124,315
Age 17	365	0.00025[d]	0.00008[d]	1.00[e]	1366	0.50	1	133,270
Age 18	365	0.00025[d]	0.00008[d]	1.00[e]	1456	0.50	1	142,034
Age 19	365	0.00025[d]	0.00008[d]	1.00[e]	1543	0.50	1	150,579

Age 20	365	0.00025[d]	0.00008 [d]	1.00[e]	1628	0.50	1	158,883
Age 21	365	0.00025[d]	0.00008 [d]	1.00[e]	1711	0.50	1	166,927
Age 22	365	0.00025[d]	0.00008 [d]	1.00[e]	1790	0.50	1	174,697
Age 23	365	0.00025[d]	0.00008 [d]	1.00[e]	1867	0.50	1	182,185
Age 24	365	0.00025[d]	0.00008 [d]	1.00[e]	1941	0.50	1	189,383
Age 25	365	0.00025[d]	0.00008 [d]	1.00[e]	2012	0.50	1	196,288
Age 26	365	0.00025[d]	0.00008 [d]	1.00[e]	2079	0.50	1	202,900
Age 27	365	0.00025[d]	0.00008 [d]	1.00[e]	2144	0.50	1	209,219
Age 28	365	0.00025[d]	0.00008 [d]	1.00[e]	2206	0.50	1	215,250
Age 29	365	0.00025[d]	0.00008 [d]	1.00[e]	2265	0.50	1	220,996
Age 30	365	0.00025[d]	0.00008 [d]	1.00[e]	2321	0.50	1	226,464
Age 31	365	0.00025[d]	0.00008 [d]	1.00[e]	2374	0.50	1	231,661
Age 32	365	0.00025[d]	0.00008 [d]	1.00[e]	2425	0.50	1	236,594
Age 33	365	0.00025[d]	0.00008 [d]	1.00[e]	2473	0.50	1	241,272
Age 34	365	0.00025[d]	0.00008 [d]	1.00[e]	2518	0.50	1	245,704
Age 35	365	0.00025[d]	0.00008 [d]	1.00[e]	2561	0.50	1	249,899
Age 36	365	0.00025[d]	0.00008 [d]	1.00[e]	2602	0.50	1	253,866
Age 37	365	0.00025[d]	0.00008 [d]	1.00[e]	2640	0.50	1	257,614
Age 38	365	0.00025[d]	0.00008 [d]	1.00[e]	2676	0.50	1	261,154
Age 39	365	0.00025[d]	0.00008 [d]	1.00[e]	2711	0.50	1	264,494
Age 40	365	0.00025[d]	0.00008 [d]	1.00[e]	2743	0.50	1	267,644

[a] Unless otherwise noted, all values from EPRI (2012), Table 5-80 & 81.
[b] Adjusted to stable population as described in Attachment C.
[C] These stage weights determined by interpolation assuming a constant instantaneous growth rate.
[d] Assumed species moderately exploited by commercial and recreational fishermen (m = 0.75z; f=0.25z).
[e] Assumed value based on best professional judgement.

Table 11 B-4 Life history parameters for gizzard shad used to calculate equivalent losses[a]

Age/Stage	Duration	Natural Mortality Rate (M)	Fishing Mortality Rate (F)	Fishing Vulnerability	Weight at Beginning (g)	Fraction Female	Fraction Mature	Annual Egg Production per Female
Egg	2	0.4480[b]	0.0000	0.00	0.0001			
YSL	10	0.2390[b]	0.0000	0.00	0.0001			
PYSL	17	0.2390[b]	0.0000	0.00	0.0008[c]			
Ent. Juv	40	0.0130[b]	0.0000	0.00	0.0612			
Age 0	296	0.0130[b]	0.0000	0.00	0.0854[c]			
Age 1	365	0.0025	0.0000	0.00	21	0.50	0.50	59,482
Age 2	365	0.0025	0.0000	1.00	110	0.50	1.00	341,997
Age 3	365	0.0025	0.0000	1.00	227	0.50	1.00	341,997
Age 4	365	0.0025	0.0000	1.00	319	0.50	1.00	341,997
Age 5	365	0.0025	0.0000	1.00	409	0.50	1.00	341,997
Age 6	365	0.0025	0.0000	1.00	513[c]	0.50	1.00	341,997
Age 7	365	0.0025	0.0000	1.00	611[c]	0.50	1.00	341,997

[a] Unless otherwise noted, all values from EPRI (2012), Table 5-87 & 89.
[b] Adjusted to stable population as described in Attachment C.
[c] These stage weights determined by interpolation assuming a constant instantaneous growth rate.

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Appendix 11 C

40 CFR 122.21(r)(11) – Benefits Valuation Study

Methods Used to Establish Stable Population Parameters

The assumption that each life table of each Target Taxa reflected a stable population was checked using standard life-table calculations adapted from Gotelli (1995) and corrected, if necessary, using the steps below: {Note: Stages (age < 1 year) are indexed by *i* and have values E (eggs), Y (yolk-sac larvae), P (post yolk-sac larvae), and J (juvenile). Ages 1 and older are indexed by *x*, and have values reflecting Ages 1 to k.}

1. Survival from egg to Age 1 ($S_{E\rightarrow 1}$) was calculated using estimates from the scientific literature:

   $$S_{E\rightarrow 1} = e^{-\sum_{i=E}^{J} d_i M_i} = S_{i=E} S_{i=Y} S_{i=P} S_{i=J}$$

   where:
   d_i = duration of stage *i* in days; and,
   M_i = available daily instantaneous mortality rate of stage *i* from the scientific literature.

2. The net reproductive rate (R_0) of the adults was calculated as follows:

   $$R_0 = S_{E\rightarrow 1} \sum_{x=1}^{k} S_{1\rightarrow x}\, b_x$$

   where:
   $S_{1\rightarrow x}$ = survival from age 1 to age $x = e^{-\sum_1^x d_x M_x}$; and
   b_x = average number of eggs produced by an individual of age *x* (incorporates age-specific sex ratio, female maturity rate, and fecundity);
   k = maximum age.

3. Using the estimates developed above, the population generation time was calculated as follows:

   $$G = \frac{S_{E\rightarrow 1} \sum_{x=1}^{k} x S_{1\rightarrow x} b_x}{R_0}$$

4. Next, calculate the rate of population increase as follows:

   $$r \approx \frac{\ln(R_0)}{G}$$

5. Lastly, if *r* was not approximately 0 ($R_0 \approx 1$), then all stage mortality rates (M_i) that comprise $S_{E\rightarrow 1}$ were multiplied by a constant (C) to balance the life history (i.e., population size is stable):

   $$C = -\frac{\ln\left(\frac{1}{\sum_{x=1}^{k} S_{1\rightarrow x} b_x}\right)}{\sum_{i=E}^{J} d_i M_i}.$$

Appendix 13 A
40 CFR 122.21(r)(13) – Peer Review

Biology Reviewer Resume

LAWRENCE W. BARNTHOUSE, Ph. D.

President and Principal Scientist
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Adjunct Associate Professor of Biology
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Education

Ph.D., Biology, University of Chicago, Chicago, Illinois, 1976
A.B., Biology, Kenyon College, Gambier, Ohio, 1968

Work History

1976-1995:	Research Staff Member, Environmental Sciences Division, Oak Ridge National Laboratory
1995-1998:	Principal Scientist, McLaren-Hart, Inc.
1998: -	President and Principal Scientist, LWB Environmental Services, Inc.

Experience Summary

Dr. Barnthouse is the President and Principal Scientist of LWB Environmental Services, Inc. He formerly spent 19 years as a research staff member and Group Leader at Oak Ridge National Laboratory, where he was involved in dozens of environmental research and assessment projects involving development of new methods for predicting and measuring environmental risks of energy technologies. After leaving Oak Ridge National Laboratory in 1995, he spent two and a half years with McLaren-Hart, Inc. prior to establishing LWB Environmental Services.

Dr. Barnthouse has authored or co-authored approximately 100 publications relating to ecological risk assessment. He is a Fellow of the American Association for the Advancement of Science, former Hazard/Risk Assessment Editor of the journal *Environmental Toxicology and Chemistry*, and Founding Associate Editor of the journal *Integrated Environmental Assessment and Management*. He served as an external peer reviewer and issue paper author during the development of the U.S. Environmental Protection Agency's (EPA) guidelines for ecological risk assessment, and has also served on peer review panels for several EPA site-specific risk assessments.

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MAJOR PROJECTS

Impacts of Cooling Water Withdrawals on Aquatic Populations and Communities

Site-specific Activities

- **Technical expert on impingement and entrainment impact assessment for the Bruce Power Nuclear Station.** Working with client and Canadian regulatory agencies to develop a method for scaling restoration projects needed to offset impingement and entrainment losses in compliance with the Canadian Fisheries Act. Now assisting in the design of biomonitoring programs associated with two major dam removal actions. Monitoring will document the quantity of new fish production provided by the dam removals and determine whether this production is sufficient to offset station losses.

- **Lead biologist, Indian Point Nuclear Station permitting/relicensing program** Designed technical assessment approach for using 40 years of riverwide monitoring data to address impacts of station operations on Hudson River fish populations; led biological evaluation of alternative technologies for reducing entrainment and impingement mortality; led R&D program demonstrating the potential effectiveness of cylindrical wedgewire intake screens for reducing entrainment. Testified at New York State Department of Environmental Conservation regulatory hearings, October 2011, January 2012, July 2012, July 2013, and September, 2015. Recently contributed to a synthesis report documenting the results of four decades of research on Hudson River fish populations.

- **External reviewer of EPA and consultant reports related to NPDES permitting at a the Merrimack Generating Station** Engaged by facility owner to provide independent advice concerning strengths and weaknesses in EPA and consultant-generated reports concerning ecological impacts of entrainment, impingement, and thermal discharges from the facility.

- **Technical expert on impacts of power plants on Long Island Sound fish populations.** Engaged as expert witness by owners of two New England nuclear power plants to testify concerning impacts of their plants on winter flounder and American shad populations. Testified at State of Vermont Environmental Court regarding impacts of client's thermal discharge on American shad migration in the Connecticut River, June 2007. Testified before the Vermont Public Services Board, June 2013.

- **Technical expert on impacts of the Danskammer Generating Station on Hudson River fish populations.** Testified as an expert witness at permit hearings, November-December 2005.

- **Technical expert on impacts of power plants on Cape Cod Bay fish populations.** Engaged by owners of the Pilgrim Nuclear Station to perform technical analyses and testify concerning impacts of their plant on winter flounder and other susceptible fish populations.

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- **Technical Team Leader, 316(b) assessment for the Salem Generating Station.** Responsible for developing methods for quantitative assessment of impacts of entrainment and impingement on estuarine fish species; directed the analysis of data relating to entrainment and impingement impacts to support the facility owner's 1999 and 2006 permit renewal applications.

- **Technical expert on 316(a) and 316(b) issues at the Diablo Canyon Power Plant.** Reviewed historical predictive and retrospective thermal effects assessment studies; provided expert review of draft 316(b) Demonstration. Represented client at regional water board hearing, March 2001.

- **Technical advisor and expert witness for EPA Region II in NPDES permit hearings related to impacts of fossil and nuclear power plants on fish populations in the Hudson River.** Assisted EPA lawyers in preparation of case, performed independent data evaluations and model-based analyses, testified in administrative law hearings, 1977-1980. Represented EPA on a technical team that assisted EPA, the State of New York, and the Consolidated Edison Co. in the negotiation of a widely publicized settlement agreement. Became senior editor for an American Fisheries Society monograph presenting scientific results from 10 years of monitoring and research on the Hudson. Assessment methods developed for the "Hudson River Power Case" are now used by utility companies and regulatory agencies throughout the United States.

Research and Regulatory Support Related to Section 316(b) of the Clean Water Act

- **316(b)-related research performed for the Electric Power Research Institute.** Five major projects from 2003 through the present that provided EPRI member companies with biological data and assessment methods needed to comply with state and federal intake structure regulations. Published peer-reviewed journal article on valuing ecological resources potentially affected by entrainment and impingement. Currently engaged in a project that will provide advice to EPRI and regulatory agencies concerning updating the 1977 316(a) guidance to reflect recent experience and new scientific developments.

- **Comments on proposed EPA regulations.** Contributed to comments submitted by the Utility Water Act Group (UWAG) and the Electric Power Research Institute (EPRI) on proposed 316(b) rules, information requests, and survey documents, 2002, 2005, 2008, 2010, and 2011.

Other related activities

- **Technical expert on entrainment impact assessment for Gulf of Mexico LNG terminals.** Provided advice to two major corporations concerning the validity of data and methods used to predict impacts of proposed offshore LNG terminals on Gulf of Mexico fishery resources, and on the design of baseline monitoring programs for these facilities.

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- **Technical expert on fisheries impacts at the proposed Calypso LNG terminal.** Engaged by company preparing Environmental Impact Statement to provide oversight on the fisheries impact component of the EIS.

CERCLA/RCRA/NRDA

- **Technical expert on NRDA, Portland Harbor Superfund site.** Engaged to evaluate the contribution of the client's site to alleged natural resource injuries in the Willamette River, Oregon. Key scientific issues involve validity of ecotoxicity data and habitat classification scheme used to estimate service reductions resulting from chemicals associated with client's facility.

- **Senior ecologist, restoration of the southeastern Tennessee Copper Basin.** The project involves development and implementation of an adaptive management-based watershed restoration plan for the North Potato Creek Watershed, Tennessee, which was seriously degraded by historic mining and smelting activities. This project was recently cited by the National Academy of Sciences as an example that should be followed at other large, complex sites.

- **Technical expert on ecological risk assessment and NRDA for General Electric Co. operations in New York and Massachusetts**. The project involved support of CERCLA risk assessment and Natural Resource Damage Assessment activities relating to historic discharges of PCBs to the Hudson and Housatonic Rivers.

- **Technical expert on NRDA, Tar Creek Superfund site.** Engaged to evaluate natural resource injuries related to mining activities in northeastern Oklahoma.

- **Technical expert on ecological risk assessment and NRDA for pulp mill in eastern North Carolina**. Provided confidential comments to facility owner concerning validity of ecological risk assessments performed by consultants to the owner and by the U.S. Environmental Protection Agency; advised the owner concerning the types and magnitudes of potential natural resource damage liabilities due to contamination of sediment by dioxins and mercury.

- **Technical advisor, remediation of contaminated sediment at Langley AFB, Virginia**. Provided advice to remediation team concerning (1) establishment of cleanup goals in lead and PCB-contaminated sediment, and (2) development of a post-remediation monitoring program involving measurement of lead concentrations in fish and mussels. Assisted client in obtaining EPA approval of cleanup goal.

- **Senior Technical Advisor for an assessment of ecological risks of chlorinated solvents, heavy metals, mercury, and PCBs at a chemical manufacturing facility in southwest Louisiana**. Responsible for selection of risk assessment methodologies used by team of risk assessors evaluating on-site and off-site risks to fish, wildlife, and sediment-dwelling biota.

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Developed a strategy for negotiating major elements of the project work plan with EPA Region VI. Responsible for defining strategy for integrating results of ecological risk assessment into corrective measures planning and potential NRDA defense activities.

- **Group leader for ecological risk assessment team performing CERCLA baseline ecological risk assessments for U.S. Department of Energy facilities in Oak Ridge, Tennessee, Portsmouth, Ohio, and Paducah, Kentucky (EPA Regions IV and V).** Major assessments included a five-year investigation and baseline risk assessment for the Clinch River, Tennessee; reservation-wide assessments for the Portsmouth Gaseous Diffusion Plant and the Oak Ridge National Laboratory; and operational-unit-level assessments for numerous burial grounds and waste ponds.

NPDES PERMIT LITIGATION

- **Expert witness, civil lawsuit regarding pollutant discharges from power plant in western Pennsylvania**. Analyzed data and developed expert report concerning impacts of discharges on biological resources of the Conemaugh River; case settled prior to trial.

- **Expert witness, NPDES Permit action in western Pennsylvania**. Engaged by corporate client to evaluate claims that discharges from the client's steel mills have caused ecological degradation of the Allegheny and Kiskiminetas Rivers. Led technical team performing quantitative ecological risk assessment. Testified at trial, February, 2001. Prepared supplemental report following successful appeal of initial decision by client; case was settled out-of-court in November, 2004.

- **Expert witness, NPDES Permit action in Ohio**. Engaged by corporate client to evaluate allegations by federal and state agencies that discharges from the client's metal plating plant caused fish kills in the Ohio River. Charges against the client were withdrawn prior to trial.

OTHER SIGNIFICANT ACTIVITIES

- **Peer Review Coordinator, Columbia Basin PATH Project**. Organized and chaired an external review committee for a multi-stakeholder project that developed and tested models of the impacts of hydropower operations, harvesting, hatcheries, habitat quality, and oceanic conditions on endangered Snake River Basin salmonid populations. Organized an expert briefing on salmon issues for senior executives of the Bonneville Power Administration.

- **Co-principal investigator, 5-year EPA/DOE research program on ecological risk assessment methods.** This was the first federally funded research project explicitly identified as an "ecological risk assessment" project. Methods for uncertainty analysis of ecological models developed for this project were the forerunners of Monte Carlo food-chain exposure models that are widely used today. Much of the ecological risk assessment terminology now used by EPA and other agencies (e.g., "assessment endpoints" and "measurement endpoints") originated with this project. The final publication from this

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research was named the best scientific paper published at Oak Ridge National Laboratory in 1990.

- **Project manager for a basic research program on biological mechanisms underlying density-dependent population growth in fish**. The project pioneered the development and application of "individual-based population models" that are now widely used in biological research and in management of endangered species.

- **Expert advisor on ecological risk assessment for the DOE Office of Air, Water, and Radiation**. Surveyed ecological risk assessment capabilities at all major DOE facilities, initiated development of standard ecological screening benchmarks for all DOE sites, reviewed EPA draft Ecological Risk Assessment Guidance for Superfund for DOE; developed training course on Natural Resource Damage Assessment for DOE site managers, led NRDA case study project at the Savannah River Site, prepared white paper on the application of the EPA Data Quality Objectives Process at DOE sites.

Professional Society Activities

Member, Ecological Society of America, Society for Environmental Toxicology and Chemistry, American Fisheries Society

Hazard/Risk Assessment Editor, *Environmental Toxicology and Chemistry*, 1992 - 2010

Founding Senior Editor, *Integrated Environmental Assessment and Management*, 2004-present

Chair, SETAC Global Internet Committee, 2007-2011

Chair, SETAC/ESA Workshop on Sustainable Environmental Management, Pellston, Michigan, August 1993.

Chair, SETAC Workshop on Population-Level Ecological Risk Assessment, Roskilde, Denmark, August, 2003.

Short Course Instructor, Annual SETAC meeting

- Ecological Risk Assessment (1992, 1994)
- Product Life Cycle Assessment (1996, 1997)
- Applications of Population Biology in Ecological Risk Assessment (2008, 2010, 2012)

Chair, Applied Ecology Section, Ecological Society of America, 1995-1997

Ecological Risk Assessment Specialty Group Chair, Society for Risk Analysis, 1991-1993

Member, Advisory Panel, Society for Risk Analysis, 1996-1998

Other Professional Activities

Member, Kalamazoo River Ecological Risk Studies Peer Review Panel, 2008-

Member, Atlantic States Marine Fisheries Commission Power Plant Panel, 2001-2004

Member, External Laboratory Review Panel, EPA Midwest Ecology Division, Duluth, MN, February, 2002.

Peer reviewer, EPA Drake Chemical Site Incinerator Risk Assessment, 1998.

Member, Ecological Committee on FIFRA Risk Assessment Methodologies (ECOFRAM), 1997-2000

Reviewer and issue paper author, EPA Risk Assessment Forum Ecological Risk Assessment Guidelines Program, 1991-present

- Member of Peer Review Panel for EPA Framework for Ecological Risk Assessment
- Author of issue paper on Conceptual Model Development
- Member of Peer Review Panel for EPA Ecological Risk Assessment Guidelines
- Member of Peer Review Panel for EPA Generic Endpoints for Ecological Risk Assessment

Chair, National Research Council Workshop on Ecological Risk Assessment, Warrenton, Virginia, February 1991.

Member, National Research Council Committee on Uranium Mining in Virginia, 2010-2011.

Member, National Academy of Sciences Committee on Superfund Site Assessment and Remediation of the Coeur d'Alene River Basin, 2003-2005.

Member, National Research Council Committee on Environmental Remediation at Naval Facilities, 1997-1998.

Member, National Research Council Committee to Review the DOI's Biomonitoring of Environmental Status and Trends Program, 1994

Member, National Research Council Committee on Risk Assessment Methodology (Chair, Ecological Risk Assessment Topic Group), 1989-1993

Member, National Research Council Board on Environmental Studies and Toxicology, 1989-1992

Member, National Research Council Committee on Pesticides and Ecological Risk Assessment, 1986-1987

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International Activities:

International Union of Radioecology Ecosystem Approach Task Group Meeting, Oslo, Norway, April 2015

International Union of Radioecology Ecosystem Approach Task Group Meeting, Stockholm, Sweden, 2013

21st SETAC Europe Congress, Milan, Italy, 2011

Workshop on Population-Level Ecological Risk Assessment, 12th SETAC Europe Congress, Vienna, Austria, 2002

9th SETAC Europe Congress, Leipzig, Germany, 1999

XIIIth International Plant Protection Congress, The Hague, The Netherlands, 1995

5th SETAC Europe Congress, Copenhagen, Denmark, 1995

IPPC Special Workshop on Article 2 of the U.N. Framework Convention on Climate Change, Fortaleza, Brazil, 1994

SGOMSEC Workshop on Methods to Assess the Effects of Chemicals on Ecosystems, Montpellier, France, 1994

IAEA Validation of Assessment Models Project, Vienna, Austria, 1992

International Biospheric Model Validation Project, Vienna, Austria, 1992

Seventh International Congress of Pesticide Chemistry, Hamburg, Germany, 1990

Workshop on Ecological Risk Assessment for Chemicals, Schmallenburg, West Germany, 1987

NATO Conference on Safety Assurance for Environmental Introductions of Genetically-Engineered Organisms, Rome, 1987

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Awards and Honors

- Martin Marietta Energy Systems Technical Achievement Award, 1991
- Martin Marietta Energy Systems Author of the Year, 1991
- Martin Marietta Energy Systems Technical Achievement Award, 1994
- Fellow, American Association for the Advancement of Science, 1994

Publications

Books and Monographs

Barnthouse, L. W., W. R. Munns, and M. T. Sorensen (eds.). 2007. *Population-Level Ecological Risk Assessment.* Taylor & Francis, Boca Raton, Florida, U.S.A.

Barnthouse, L. W., G. R. Biddinger, W. E. Cooper, J. A. Fava, J. H. Gillett, M. M. Holland, and T. F. Yosie (eds.) 1998. *Sustainable Environmental Management.* SETAC Press, Pensacola, Florida, U.S.A.

Barnthouse, L. W., J. Fava, K. Humphres, R. Hunt, L. Laibson, S. Noeson, J. Owens, J. Todd, B. Vigon, K. Weitz, and J. Young. 1997. *Life-Cycle Impact Assessment: The State-of-the-Art.* SETAC Press, Pensacola, Florida, U.S.A.

Barnthouse, L. W., R. J. Klauda, D. S. Vaughan, and R. L. Kendall (eds.) 1988. *Science, Law, and Hudson River Power Plants: a Case Study in Environmental Impact Assessment.* American Fisheries Society Monograph 4. American Fisheries Society, Bethesda, Maryland, U.S.A.

Journal articles and book chapters

Barnthouse, L. W., and R. G. Stahl, Jr. 2017. Assessing and managing natural resource damages: continuing challenges and opportunities. *Environmental Management* **59**:709-717.

Barnthouse, L. W., M. Bingham, and J. Kinnell. 2016. Quantifying nonuse and indirect economic benefits of impingement & entrainment reductions at U.S. power plants. *Environmental Science & Policy* **60**:53-62.

Barnthouse, L. W. 2013. Impacts of entrainment and impingement on fish populations: a review of the scientific evidence. *Environmental Science & Policy* **31**:149-156.

Barnthouse, L. W., D. Glaser, and L. DeSantis. 2009. Polychlorinated biphenyls and Hudson River whiter perch: Implications for population-level risk assessment and risk management. *Integrated Environmental Assessment and Management* 5:435-444.

Barnthouse, L. W. 2008. The strengths of the ecological risk assessment process: Linking science to decision making. *Integrated Environmental Assessment and Management* **4**:299-305.

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Barnthouse, L. W. 2007. Population modeling. Ch. 27 in G. W. Suter II (Ed.) *Ecological Risk Assessment*, 2nd Edition. Taylor & Francis, Boca Raton, Florida, USA.

Barnthouse, L. W. 2004. Quantifying population recovery rates for ecological risk assessment. *Environmental Toxicology and Chemistry* **23**:500-508.

Suter, G. W. II, S. B. Norton, and **L. W. Barnthouse**. 2003. The evolution of frameworks for ecological risk assessment from the Red Book ancestor. *Human and Ecological Risk Assessment* **9**:1349-1360.

Barnthouse, L. W., D. Glaser, and J. Young. 2003. Effects of historic PCB exposures on the reproductive success of the Hudson River striped bass population. *Environmental Science and Technology* **37**:223-228

Barnthouse, L. W., D. G. Heimbuch, V. C. Anthony, R. W. Hilborn, and R. A. Myers. 2002. Indicators of AEI applied to the Delaware Estuary. *The Scientific World* **2** (S1): 169-190.

Barnthouse, L. W., and R. G. Stahl, Jr. 2002. Quantifying natural resource injuries and ecological service reductions: challenges and opportunities. *Environmental Management* **30**:1-12.

Suter, G. W. II, and **L. W. Barnthouse**. 2001. Modeling toxic effects on populations: Experience from aquatic studies. In: Albers, P. H., G. Heinz, and H. M. Ohlendorf (eds.), *Environmental Contaminants and Terrestrial Vertebrates: Effects on Populations, Communities, and Ecosystems*, pp. 177-188. SETAC Special Publication Series, Society of Environmental Toxicology and Chemistry, Pensacola, FL, USA.

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Barnthouse, L. W. 2000. Impacts of power-plant cooling systems on estuarine fish populations: The Hudson River after 25 years. *Environmental Science & Policy* **3**:S341-S348.

K. A. Rose, L. W. Brewer, **L. W. Barnthouse**, G. A. Fox, N. W. Gard, M. Mendonca, K. R. Munkittrick, and L. J. Vitt. 1999. Ecological responses of oviparous vertebrates to contaminant effects on reproduction and development. Ch. 4. IN: Di Giulio, R. T., and D. E. Tillitt (eds.). *Reproductive and Developmental Effects of Contaminants in Oviparious Vertebrates*. SETAC Press, Pensacola, Florida.

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Jones, D. S., **L. W. Barnthouse**, G. W. Suter II, R. A. Efroymson, J. M. Field, and J. J. Beauchamp. Ecological risk assessment in a large river-reservoir: 3. Benthic invertebrates. *Environmental Toxicology and Chemistry* **18**:599-609.

Barnthouse, L. W. 1998. Modeling ecological risks of pesticides: a review of available approaches. Pp. 769-798 in Chapter 24 in H. Schüürmann and B. Markert (eds.) *Ecotoxicology*. Spektrum Academic Publishers, Heidelberg.

Jaworska, J. S., K. A. Rose, and **L. W. Barnthouse**. 1997. General response patterns of fish populations to stress: an evaluation using an individual-based simulation model. *Journal of Aquatic Ecosystem Stress and Recovery* 6:15-31.

Barnthouse, L. W. 1995. A framework for ecological risk assessment. pp. 367-360 in R. A. Linthurst, P. Bourdeau, and R. G. Tardiff (eds.) *Methods to Assess the Effects of Chemicals in Ecosystems*. John Wiley & Sons, Chichester, England.

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Suter, G.W. II, and **L.W. Barnthouse**. 1993. Assessment Concepts, pp 21-48 in G.W. Suter (ed.) *Ecological Risk Assessment*. Lewis Publishers, Chelsea, Michigan.

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Jones, T.D., B.A. Owen, J.R. Trabalka, **L.W. Barnthouse**, C.E. Easterly, and P.J. Walsh. 1991. Chemical pollutants: a caricaturized logos for future planning. *Environmental Auditor* 2:71-88.

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DeAngelis, D.L., **L.W. Barnthouse**, W. Van Winkle, and R.G. Otto. 1990. A critical appraisal of population approaches in assessing fish community health. *Journal of Great Lakes Research* 16(4):576-590.

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Hunsaker, C.T., R.L. Graham, G.W. Suter II, R.V. O'Neill, **L.W. Barnthouse**, and R.H. Gardner. 1990. Assessing ecological risk on a regional scale. *Environmental Management* 14:324-332.

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Hildebrand, S.G., **L.W. Barnthouse**, and G.W. Suter II. 1987. The role of basic ecological knowledge in environmental assessment. pp. 51-70 IN: Draggen, S., J.J. Cohrsen, and R.E. Morrison (eds), *Preserving Ecological Systems*, Pareger, New York.

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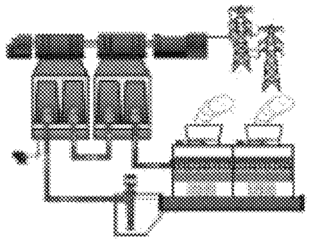
Appendix 13 B
40 CFR 122.21(r)(13) – Peer Review

Engineering Reviewer Resume

J. W. CUCHENS, P.E.
Principal Consultant / Cooling Systems
B.S., Mechanical Engineering,
Mississippi State University, 1973



EXPERIENCE SUMMARY

Mr. Cuchens has over 45 years of experience in all phases of power plant design, construction and operation with various types of generating units including nuclear, fossil, and co-generation facilities. Engineering experience includes conducting conceptual design studies, equipment design specifications, and procurement/bid evaluations. His experience includes design of major plant equipment including the turbine/thermal cycle equipment, boiler and draft system equipment, and plant cooling system equipment. Experience within the past 42 years has primarily been associated with power plant cooling systems which consist of cooling towers, cooling ponds/lakes, steam-surface and air-cooled condensers, air removal/vacuum systems, auxiliary heat exchangers, cooling water pumps/sumps, service water equipment, and related piping systems. Mr. Cuchens experience also specialized in the development and use of computer simulation models for performance analysis of the cooling systems/components.

RELATED EXPERIENCE

Power Engineering experience includes optimization of thermal/power island cycle in support of resource forecast modeling (future generation plans) for various types of generation including fossil fuel units; pulverized fluidized bed units; gas fired/combined cycle units; and nuclear units. Mr. Cuchens Power engineering experience supported the development of numerous power generation projects as shown in the project list below.

Steam Cycle / Balance of Plant Design experience includes the development of thermal cycle configurations including feedwater heater and balance of plant equipment configurations. Additional steam cycle engineering experience includes evaluation of turbine design criteria for once-through and closed-loop cooling cycles in establishing guaranteed performance parameters. Additional steam cycle experience includes the evaluation of steam cycle performance constraints and limitations with consideration of equipment design (single pressure, multipressure, etc.) and site specific conditions (climatology, geology, etc.).

Cooling Cycle Design experience includes various types of technical/feasibility studies which became the basis in development of equipment technical specifications, bid evaluations, and applied research of cooling cycle equipment technology. Mr. Cuchens' experience also consisted of design and operating knowledge for various types of cooling cycles including closed loop, once-through, and/or cooling ponds, serving nuclear units, fossil units, and cogeneration units. Mr. Cuchens design experience involved the optimization of the cooling system equipment (towers, pumps, and condensers) for new and/or existing units with consideration of performance, capital cost, and operation and maintenance. His expertise includes development of computer programs for selection of cooling cycle equipment design as well as analysis of equipment and/or plant performance.

J. W. Cuchens, P.E.

Cooling Tower experience includes the design of natural draft and/or mechanical draft cooling towers for numerous power generating facilities. Design experience includes the development of tower design standards for utilization of concrete, wood, and/or fiberglass construction materials for both cross-flow and counter-flow type cooling towers. Cooling tower experience includes consulting services to plant personnel (field inspections, equipment trouble shooting, etc.) in support of operations and maintenance activities. Cooling tower experience includes field testing for development of a system data base for in-depth analysis of tower thermal design and evaluation of vendor proposals. Cooling tower experience includes feasibility studies for modifying and/or upgrading existing towers for enhancing tower performance and reducing operations and maintenance costs. Retrofit experience includes refurbishing existing cooling towers as well as installation of helper cooling towers for supplementing existing tower performance. Mr. Cuchens experience provided enhanced tower/unit performance capability throughout the Southern Electric system.

Condenser Design experience involved the design of both air-cooled and steam surface condensers including single pressure, multi-pressure, single pass, and multi-pass configurations. Mr. Cuchens' experience includes the development of condenser design standards for field erected and modular type condenser construction. Mr. Cuchens provided field inspection/consulting services to plant personnel (tube inspections, air leakage trouble shooting, etc.) in support of operations and maintenance (O&M) and plant outage activities. Mr. Cuchens directed and/or participated in field testing to assess condenser tube cleanliness and overall condenser performance. Mr. Cuchens was responsible for conducting feasibility studies for modifying and/or upgrading condensers to enhance overall system/unit performance. Mr. Cuchens retrofit experience involved numerous re-tubing projects (modular and conventional) as well as condenser waterbox and hotwell replacement.

Circulating Water Pumps/System Design experience includes the engineering design of various types of circulating water pumps and piping systems including mixed-flow vertical can-type pumps and vertical volute type pumps. Mr. Cuchens expertise includes the capability for providing hydraulics analysis for determination of system pumping head requirements as well as the testing and evaluation of pump performance. Pump design experience includes development of pump design standards for closed suction systems as well as open pit sump designs. Mr. Cuchens has been responsible for conducting feasibility studies for modifying and/or upgrading existing pumps for enhancing pump/condenser flow. Retrofit experience includes refurbishing existing pump impellers as well as and installation of new pump rotating assemblies and modification of pump motors. Mr. Cuchens provided guidance in best practices associated with the design of pump sumps based on sump model studies to mitigate vortex issues.

ENVIRONMENTAL PROJECTS & INDUSTRY RELATED EXPERIENCE

EPA 316b Experience - Mr. Cuchens has been actively engaged in addressing EPA 316b rule provisions in efforts to integrate industry experience related to best practices in water use/consumption, protection of aquatic species, and application of alternative cooling system technologies which promote and support environmentally compliant and efficient cooling systems. As the Principal Engineer for Southern Company, Mr. Cuchens has conducted and/or directed engineering studies in support of compliance with 316(b) including for the system fleet including closed loop cycle conversion, use of treated effluent (greywater) water sources, and/or modified intake systems with fish-friendly traveling water screens.

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J. W. Cuchens, P.E.

Subsequent to employment as the Principal Engineer of cooling systems with the Southern Company for 42 years, Mr. Cuchens has acted as the Principal Consultant of Cuchens & Associates. Mr. Cuchens has been contracted by several A/E and/or Environmental Firms and/or Utilities to conduct peer reviews associated with compliance of EPA 316(b) - 40 CFR 122.21 (r)(5), (r)(10), (r)(12), and (r)(13). The scope of peer review varies subject to the type of facility, complexity of options evaluated, and charge questions applicable to site specifics.

Peer reviews include reports include reports generated for industrial and/or utility/power generation facilities. Customer/client information can be provided upon request under confidential agreement.

Anti-Fouling Fill Media Research - Film fill media designs used in counter-flow type cooling towers have a tendency to foul or plug under certain water chemistry conditions. Mr. Cuchens has been involved for ~ 20 years in the research and investigation of anti-fouling fill designs for prevention of fouling in counterflow cooling towers. Mr. Cuchens has also been involved in the investigation of the use of surfactants to enhance cross-flow cooling tower performance. The results of these in-situ programs have provided long term reliable cooling tower performance with minimal fouling.

Industry Related Experience & Training

Mr. Cuchens has participated in and authored numerous papers and articles for EPRI Cooling System Conferences, Cooling Technology Conferences, International Water Conferences, Industry Trade Magazines, and Educational Seminars. Mr. Cuchens has conducted numerous training seminars related to cooling tower/condenser technology.

Industrial / Process Engineering

Mr. Cuchens experience includes design and maintenance support for various cooling systems and/or process heat exchanger systems for refineries and cogeneration facilities. Experience included refurbishment and/or replacement of heat exchanger and/or cooling systems components for enhanced production capability. Experience also included inspection of plant systems and vendor oversite for minimizing turnaround duration and associated costs. Mr. Cuchens experience also includes design and construction support for an Integrated Gasified Combined Cycle (IGCC) facility.

Component Specifications Experience

Mr. Cuchens experience includes the development of design specifications and construction oversight for various components of plant cooling systems serving power industry/utility and industrial facilities including but not limited to the following:

1. Cooling Tower Specifications
   a. Mechanical Draft (crossflow and counterflow)
   b. Natural Draft Towers (crossflow and counterflow)
   c. Wood, Concrete, Fiberglass construction & repair
2. Condenser Specifications
   a. Steam surface condenser installation/construction
   b. In-field construction or shop assembled construction

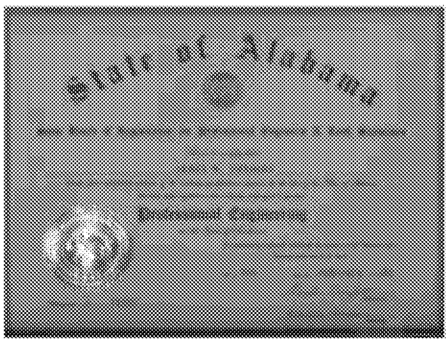
J. W. Cuchens, P.E.

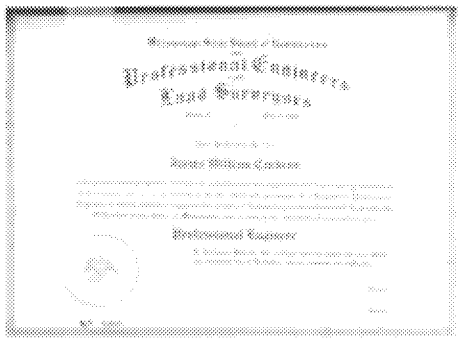
c. Retubing specifications
d. Hotwell Replacement
e. Modular Bundle replacement
f. Turnkey retrofit (tubes, coating, staking, etc.)
g. Air Cooled condenser/heat exchangers
h. Air removal Equipment (SJAE/Vacuum Pumps, etc.)

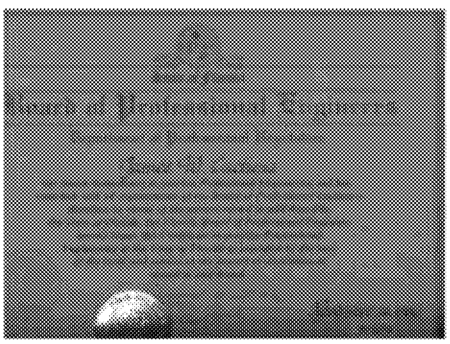
3. Circulating Water Pumps
   a. New pump installation
   b. Retrofit pump installation
   c. Pump component replacement (impellers, shaft, etc.)

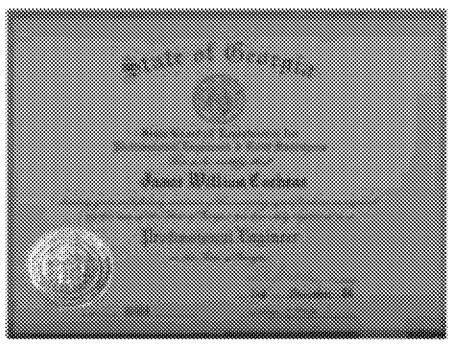
CERTIFICATIONS AND AFFILIATIONS

Registered Professional Engineer in Four States
Alabama PE # 13752; Florida PE # 37709; Georgia PE # 16164; Mississippi PE #09905
American Society of Mechanical Engineers – Member and Committee Representative
Cooling Tower Institute - Board of Directors 1995-2001; 2012-2016 (Current)
Cooling Tower Institute - Vice President 2001, President 2000
Cooling Tower Institute – Engineering Standards & Maintenance Committee - Chairman
ASME - Power Test Code (PTC) 23 – Cooling Tower Test Code - Committee Member
ASME - Power Test Code (PTC) 30 – Air Cooled Condenser Test Code - Committee Member









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J. W. Cuchens, P.E.

PROJECT EXPERIENCE (PARTIAL)

The following is a partial experience list of various generation and/or retrofit projects involving cooling system components (Cooling Towers, Condensers, CW Pumps/Sumps, Air Removal Systems, etc.)

Bowen Units 1-4 Cooling Systems W/ Natural Draft Towers – Repack/Refurbishment
Scherer Units 1-4 Cooling Systems W/ Natural Draft Towers – Repack/Refurbishment
Vogtle Units 1 & 2 Cooling Systems W/ Natural Draft Towers – Repair/Refurbishment
Vogtle Units 3 & 4 AP1000 Cooling Systems W/ Natural Draft Towers – Under Construction
Millers Units 1 & 2 Cooling Systems W/ Crossflow Natural Draft Tower - Refurbishment
Millers Units 3 & 4 Cooling Systems W/ Counterflow Natural Draft Tower - Refurbishment
Plant Hatch Nuclear Units 1 & 2 – Tower Replacement/Retrofit
Plant Farley Nuclear Units 1 & 2 – Tower Replacement/Retrofit
Crist Steam Plant Units 6 & 7 Cooling Tower Retrofit/Replacement
Watson Steam Plant Unit 5 - Cooling Tower Retrofit/Replacement
Watson Steam Plant Unit 4 – Environmental Cooling Tower – Installation/Repair
Wansley Units 1&2 - Crossflow Concrete Tower – Repack/Refurbishment
Gaston Unit 5 - Crossflow Concrete Tower – Repack/Refurbishment
Sweatt Units 1&2 - Crossflow Wood Tower – Repack/Refurbishment
Plant Branch Units 1 & 2 – Environmental Cooling Tower
Plant Yates Units 1 - 4 Cooling Tower Retrofit - Open/Closed Loop Conversion
Plant McDonough Units 1 & 2 Cooling Tower Retrofit - Open/Closed Loop Conversion
Combined Cycle (CC) Cooling Systems Experience Including Cooling Towers, Condensers, Cooling Water Pumps, Vacuum Systems, and Related Auxiliaries

- Barry CC Units 6 & 7
- Daniel CC Units 3 & 4
- Wansley CC Units 6 & 7
- Lansing Smith CC Unit 3
- Plant Harris CC Units 1 & 2
- Plant Franklin CC Units 1, 2, & 3
- Plant Theodore Cogeneration Unit
- Olin/Washing County Cogeneration Unit
- McIntosh CC Units 10 & 11
- Plant McDonough CC Units 3, 4, & 5
- Kemper County Integrated Gasified Combined Cycle (IGCC)

PROJECT EXPERIENCE (CONTINUED)

Daniel Units 1 & 2 Condenser Retube (Titanium)
Watson Units 4 & 5 Condenser Retube (Titanium)
Crist Units 6 & 7 Condenser Retube (Titanium)
Yates 7 Condenser Retube (Titanium)
Plant Hatch Nuclear Units 1 & 2 Condenser Retube (Titanium)
Gaston Units 1, 2 & 3 Condenser Retube (SeaCure, 90/10 CuNi, & Titanium)

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J. W. Cuchens, P.E.

Crist Units 6 CW Pump Replacement/Retrofit
Watson Unit 5 CW Pump Replacement/Retrofit
McIntosh 11 – Cooling Tower On-Line Replacement (Tornado Destruction)t
Crist 6 & 7, Watson 4 & 5 – Cooling Tower Repair - Hurricane Destruction
Miller Units 3 & 4 – On-Line Cooling Tower Fill Replacement
Chevron Refinery – Process Cooling & Chevron Cogeneration Facility
Olin Chemical Plant - Process Cooling & Washington County Cogeneration Facility
Mitsubishi Polycrystalline Chemical Plant & Theodore Cogeneration Facility
Kemper County IGCC Facility

316(b) - 40 CFR 122.21 (r)(5), (r)(10), (r)(12), Project Experience (Incl. Compliance Studies)

Plant Crist – Units 1-5 (Gulf Power Company
Lansing Smith Steam Plant – Units 1&2 (Gulf Power Company)
Barry Steam Plant – Units 1-5 (Alabama Power Company)
Gorgas Steam Plant – Units 1-10 (Alabama Power Company)
Gaston Steam Plant – Units 1-4 (Alabama Power Company)
Green County Steam Plant – Units 1 & 2 (Alabama Power Company)
Watson Steam Plant – Units 1-4 (Mississippi Power Company)
Daniel Steam Plant – Units 1&4 (Mississippi Power Company)
McIntosh Steam Plant – Units 1&2 (Georgia Power Company)
Scherer Steam Plant – Units 1-4 (Georgia Power Company)

Dania Beach Energy Center (Florida Power & Light)
Culbreath Bayside Power Station (Tampa Electric Company)

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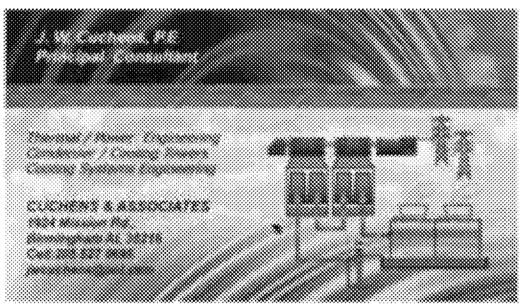

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Appendix 13 C
40 CFR 122.21(r)(13) – Peer Review

Economics Reviewer Resume

August 2019

FRANK LUPI
Curriculum Vitae

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EDUCATION

Ph.D., Applied Economics, with Economics minor, 1997, University of Minnesota, Minneapolis.
M.S., Agricultural Economics, 1988, University of Illinois, Urbana.
B.S., Economics, 1986, University of Illinois, Urbana.

EMPLOYMENT

Professor 2009–, Assoc. Prof. 2003-09, Asst. Prof. 1999-03, Michigan State University, Dept of Agricultural, Food and Resource Economics (60%) & Dept of Fisheries and Wildlife (40%)

Named as a William J Beal Outstanding Faculty member, 2018

Visiting Assistant Professor, 1997-1998, Michigan State University, Dept. of Agricultural Economics
Visiting Specialist, 1993-1997, Michigan State University, Department of Agricultural Economics
Graduate Research Assistant, 1988-1992, University of Minnesota, Department of Applied Economics
Graduate Research Assistant, 1986-88, Univ. of Illinois, Agric. Economics & Inst. for Environ. Studies

Faculty affiliations

Partnership for Ecosystem Research and Management (PERM) program between MSU and the Michigan Department of Natural Resources and other Great Lakes agencies, 1999-present

Cooperative Institute for Great Lakes Research, 2017-present

Center for Water Sciences/MSU Water Science Network, 2008-present

Center for Systems Integration and Sustainability, 2006-present

Environmental Science and Policy Program, MSU, 2003-present

Environmental and Resource Economics Specialization, MSU, 1999-present

Kellogg Biological Station, NSF Long Term Ecological Research (LTER) site, 2005-2015.

Invasive Species Initiative, MSU, 2005-2010.

Contents:

PUBLICATIONS

Journal Articles *(* indicates former student)*

1. English, E., J. Herriges, F. Lupi, K. McConnell and R. von Haefen. 2019. Fixed costs and recreation value. *American J. of Agricultural Economics.*
2. Alvarez, S., F. Lupi, D. Solis, and M. Thomas. 2019. Valuing provision scenarios of coastal ecosystem services: The case of boat ramp closings due to algae blooms in Florida, *Water*. 11(6), 1250.
3. Ansah, E.,* M. Kaplowitz, F. Lupi and J. Kerr, 2019. Smallholder participation and compliance with sustainable cocoa certification, *Agroecology and Sustainable Food Systems.*
4. Yeboah, F.,* F. Lupi, M. Kaplowitz and J. Kerr, 2019. Households' preferences for attributes of Conditional Cash Transfer programmes: A choice experiment in Ghana, *Development Policy Review*. 37:402-422.
5. English, E., R. von Haefen, J. Herriges, C. Leggett, F. Lupi, K. McConnell, M. Welsh, A. Domanski, N. Meade. 2018. Estimating the value of lost recreation days from the Deepwater Horizon oil spill. *J. Environmental Economics and Management*. 91:26-45.
6. Nolmer, J.,* F. Lupi and W. Taylor, 2018. Lakefront property owners' willingness to accept easements for conservation of water quality and habitat. *Water Resources Research*. 54(3):1533-48.
7. Yang, H.,* F. Lupi, J. Zhang, X. Chen* and J. Liu, 2018, Feedback of telecoupling: The case of a payment for ecosystem services program, *Ecology and Society*. 23(2):45.
8. Chen, X.,* F. Lupi, J. Liu, 2107. Accounting for ecosystem services in compensating for the costs of effective conservation in protected areas. *Biological Conservation*, 215:233-240.
9. Hyndman, D., et al. 2017. Quantifying changes in water use and groundwater availability in a megacity using novel integrated systems modeling, *Geophysical Research Letters*, 44.
10. Steinman, A.D., et al. 2017. Ecosystem services in the Great Lakes, *J. Great Lakes Res.* 43:161-168.
11. Gamache, C., S. Swinton, J. Herriges, F. Lupi and J. Stevenson, 2016. Solving the phosphorus pollution puzzle: Synthesis and directions for future research. *American J. of Agricultural Economics*.98: 1334-1359.
12. Yang, W.,* D. Hyndman, J. Winkler, A. Viña, J. Deines, F. Lupi, L. Luo, Y. Li, B. Basso, C. Zheng, D. Ma, S., X. Liu, H. Zheng, G. Cao, Q. Meng, Z. Ouyang, J. Liu. 2016. Urban Water Sustainability: Framework and Application. *Ecology and Society*. 21(40):4.
13. Palm-Forster, L.,* S. Swinton, F. Lupi and R. Shupp, 2016. Too Burdensome to Bid: Transaction Costs and Pay-for-Performance Conservation. *American J. of Agricultural Economics*. 98: 1334-1333.
14. Yeboah, F.,* M. Kaplowitz, J. Kerr, F. Lupi, and L. Thorp. 2016. Sociocultural and institutional contexts of social cash transfer programs. *Global Social Policy*. 16(3): 287-308.
15. Palm-Forster, L.,* F. Lupi and M. Chen, 2016. Valuing Lake Erie beaches using value and function transfers. *Agricultural and Resource Economics Review*. 45(2): 270-292.
16. Knoche, S.,* F. Lupi. 2016. Demand for Fishery Regulations: Effects of Angler Heterogeneity and Catch Improvements on Preferences for Gear and Harvest Restrictions. *Fisheries Research*. 181: 163-171.
17. Liu, W.,* C. Vogt, F. Lupi, G. He, Z. Ouyang, J. Liu. 2016. Evolution of tourism in a flagship protected area of China. *J. Sustainable Tourism*. 24, 203-226.
18. Skevas, T., N. Hayden,* S. Swinton, F. Lupi. 2016. Landowner willingness to supply marginal land for bioenergy production. *Land Use Policy*. 50, 507-517.

19. Knoche, S.,* F. Lupi, A. Suiter. 2015. Harvesting benefits from habitat restoration: Influence of landscape position on economic benefits to pheasant hunters. *Ecological Economics*. 113: 97-105.

20. Melstrom, R.,* F. Lupi, P. Esselman, R.J. Stevenson. 2015. Valuing recreational fishing quality at rivers and streams. *Water Resources Research, 51*, 140–150.

21. Yeboah, F.,* F. Lupi, M. Kaplowitz. 2015. Agricultural landowners' willingness to participate in a filter strip program for watershed protection. *Land Use Policy*. 49: 75–85.

22. Esselman, P., R. Stevenson, F. Lupi, C. Riseng, M Wiley. 2015. Landscape prediction and mapping of game fish biomass, an ecosystem service of Michigan rivers. *North American Journal of Fisheries Management*. 35:302-320.

23. Melstrom, R.,* F. Lupi. 2013. Valuing Recreational Fishing in the Great Lakes. *North American Journal of Fisheries Management* 33:1184–1193.

24. Kaplowitz, M., Lupi, F., Yeboah, F.,* K., Thorp, L. 2013. Exploring the Middle Ground between Environmental Protection and Economic Growth. *Public Understanding of Science* 22 (4): 413-426.

25. Sidique, S.,* Lupi, F., Joshi, S. V. 2013. Estimating the Demand for Drop-Off Recycling Sites: A Random Utility Travel Cost Approach. *Journal of Environmental Management*. 127: 339-346.

26. Knoche, S.,* Lupi, F. 2013. Economic Benefits of Publicly Accessible Land for Ruffed Grouse Hunters. *Journal of Wildlife Management*. 77(7):1294-1300.

27. Komarek, T.,* Lupi, F., Kaplowitz, M., Thorp, L. 2013. Influence of Energy Alternatives and Carbon Emissions on an Institution's Green Reputation. *Journal of Environmental Management*. 128:335-344.

28. Chen, X.,* Lupi, F., An, L., Sheely, R., Vina, A., Liu, J. 2012. Agent-based modeling of the effects of social norms on enrollment in Payments for Ecosystem Services. *Ecological Modelling* 229 16-24.

29. Kaplowitz, M., F. Lupi, O. Arrello* 2012. Local markets for payments for environmental services: Can small rural communities self-finance watershed protection? *Water Resources Management* 26(13) 3689-3704.

30. Ma, S.,* Swinton, S., Lupi, F., and Jolejole-Foreman, C.* 2012. Farmers' Willingness to Participate in Payment-for-Environmental-Services Programs. *Journal of Agricultural Economics* 63(3) 604–626.

31. Kaplowitz, M., Lupi, F. 2012. Stakeholder Preferences for Best Management Practices for Non-Point Source Pollution and Stormwater Control. *Landscape and Urban Planning* 104 364-372.

32. Kaplowitz, M., Lupi, F., Couper, M., Thorp, L. 2012. The Effect of Invitation Design on Web Survey Response Rates. *Social Science Computer Review* 30(3) 339-349.

33. Knoche, S.,* Lupi, F. 2012. The Economic Value of Publicly Accessible Deer Hunting Land. *Journal of Wildlife Management* 76(3) 462-470.

34. Wolf, Christopher A., Lupi, F., Harsh, S. 2011. Farmer Demand for Financial Record-Keeping System Attributes. *Agricultural Finance Review* 71 (2): 259 - 276.

35. Komarek, T.,* Lupi, F., Kaplowitz, M. 2011. Valuing Energy Policy Attributes for Environmental Management: Choice Experiment Evidence from a Research Institution. *Energy Policy* 39 5105-5115.

36. Hodin, J., F. Lupi, and M. Kaplowitz. 2010. "Complexity in Stated Choice Experiments: The Effect of Information Formats on Estimated Variances and Choice Parameters," *Journal of Agriculture and Resource Economics*. 35(3):568-590.

37. Horan, R., and F. Lupi. In 2010. "Economics of Managing and Controlling Invasive Species." *Resource and Energy Economics*. 32(4):477-482.

38. Chen, X.,* F. Lupi, A. Vinas, G. He, J. Liu, 2010. "Using Cost-Effective Targeting to Enhance the Efficiency of Conservation Investments in Payments for Ecosystem Services," *Conservation Biology*. 24(6):1469-78.

39. Knoche, S.,* and F. Lupi, 2010. "Time and Money Invested in Off-Season Deer Hunting Activities," *Human Dimensions of Wildlife*. 15:296-298.

40. Sidique, S.,* S. Joshi, and F. Lupi, 2010. "Factors influencing the rate of recycling: An analysis of Minnesota counties," *Resources, Conservation, and Recycling*. 54(4): 242-249.

41. Gramig, B.,* C. Wolf, and F. Lupi, 2010. "Understanding Adoption of Livestock Health Management Practices: The Case of Bovine Leukosis Virus." *Canadian J. of Agricultural Economics*. 58:343-360.

42. Sidique, S.,* F. Lupi, and S. Joshi, 2010. "The Effects of Behaviors and Attitude on Drop-off Recycling Activities," *Resources, Conservation, and Recycling*. 54(3): 163-170.

43. Chen, X.,* F. Lupi, G. He, and J. Liu, 2009. "Linking social norms to efficient conservation investment in payments for ecosystem services." *PNAS: Proceedings of the National Academy of Sciences*, 106 (28):11812-11817.

44. Bruggeman, D.,* M. Jones, K. Scribner, and F. Lupi, 2009. "Relating Tradable Credits for Biodiversity to Sustainability Criteria at a Landscape-Scale," *Landscape Ecology*. 24(6): 775-790.

45. Chen, X.,* F. Lupi, G. He, Z. Ouyang and J. Liu, 2009. "Factors affecting land reconversion plans following a payment for ecosystem service program," *Biological Conservation* 142(8):1740-1747.

46. Ortega-Pacheco, D.V.,* F. Lupi and M.D. Kaplowitz. 2009. "Payment for environmental services: estimating demand within a tropical watershed." *J. of Natural Resource Policy Research*. 1(2) 189-202

47. Fenichel, E.,* F. Lupi, J. Hoehn, and M. Kaplowitz. 2009. "Split-sample tests of 'no opinion' responses in an attribute based choice model," *Land Economics*. 85(2): 349-363

48. Kaplowitz, M., F. Lupi, and D. Bailey,* "Wetland mitigation banking: The banker's perspective," *Journal of Soil and Water Conservation*. 63(3) 162-172. 2008.

49. Knoche, S.* and F. Lupi. "Valuing Deer Hunting Services from Farm Landscapes." *Ecological Economics* 64(2)313-320, 2007.

50. Swain, E., P. Jakus, G. Rice, F. Lupi, P. Maxson, J. Pacyna, A. Penn, S. Spiegel and M. Veiga. "Socioeconomic Consequences of Mercury Use and Pollution." *AMBIO* 36(1) 45-61, 2007.

51. Swinton, S.M., F. Lupi, G.P. Robertson and S.K. Hamilton. "Ecosystem services and agriculture: Cultivating agricultural ecosystems for diverse benefits." *Ecological Economics* 64(2)245-52, 2007.

52. Kaplowitz, M.D., F. Lupi and J.P. Hoehn. "What does the public know about wetlands in Michigan? Using focus groups for scoping and exploratory research." *Michigan Academician* 37(19-34, 2007.

53. Kotchen, M., M. Moore, F. Lupi, and E. Rutherford. Environmental Constraints on Hydropower: An Ex-Post Benefit-Cost Analysis of Dam Relicensing in Michigan. *Land Economics*. 82:(3):384-403. 2006.

54. Swinton, S., F. Lupi, P. Robertson, and D. Landis. "Ecosystem Services from Agriculture: Looking Beyond the Usual Suspects," *American Journal of Agricultural Economics* 88:1160-1166, 2006.

55. Racevskis, L.A.,* and F. Lupi. "Comparing Urban and Rural Perceptions of and Familiarity with the Management of Forest Ecosystems," *Society and Natural Resources*. 19(6):479-495, 2006.

56. Bigford, T., et al., "Report of Resource Policy Committee: Economic Growth and Fish Conservation," *Fisheries*, 31(8):404-409, 2006.

57. Vista, A.,* P. Norris, F. Lupi and R. Bernsten. "Nutrient Loading and Efficiency of Tilapia Cage Culture

in Taal Lake, Philippines." *The Philippine Agricultural Scientist*, 89(1): 48-57, 2006.

58. Shi, H., E.J. Laurent, J. LeBouton, L. Racevskis,* K.R. Hall, M. Donovan, R.V. Doepker, M.B. Walters, F. Lupi and J. Liu. "Local Spatial Modeling of White-Tailed Deer Distributions." *Ecological Modeling*, 190:171-189, 2006.
59. Horan, R., and F. Lupi. "Economic Incentives for Controlling Trade-Related Biological Invasions in the Great Lakes," *Agricultural and Resource Economics Review*, 34(1):75-89, 2005.
60. Whitehead, J., D. Lipton, F. Lupi, and R. Southwick. "Economic Growth and Environmental Protection: A Clarification about Neoclassical Economics," *Fisheries*; 30(4):32-34, April 2005.
61. Bruggeman, D,* M. Jones, F. Lupi, and K. Scribner. Landscape Equivalency Analysis: Methodology for Estimating Spatially Explicit Biodiversity Credits, *Environmental Management*, 36(4):518-534, 2005.
62. Horan, R., and F. Lupi. "Tradable risk permits to prevent future introductions of alien invasive species into the Great Lakes," *Ecological Economics*, 52(3): 289-304, 2005.
63. Kaplowitz, M. and F. Lupi. "Color Photographs and Mail Survey Response Rates." *International Journal of Public Opinion Research*. 16:199-206, 2004.
64. Lupi, F., J. Hoehn and G. Christie. "Using an Economic Model of Recreational Fishing to Evaluate Benefits of Sea Lamprey (*Petromyzon marinus*) Control on the St. Marys River." *Journal of Great Lakes Research*. 29: 742-754. 2003.
65. Hoehn, J.P., F. Lupi, and M.D. Kaplowitz. "Untying a Lancastrian Bundle: Ecosystem Valuation in Wetland Mitigation," *Journal of Environmental Management*, 68(3):263-272, 2003.
66. Stewart, T.J., J. Bence, R. Bergstedt, M. Ebener, F. Lupi, and M. Rutter. "Recommendations for Assessing Sea Lamprey Damages: Toward Optimizing the Control Program in the Great Lakes," *Journal of Great Lakes Research*. 29: 742-754, 2003.
67. Lupi, F., M.D. Kaplowitz, and J.P. Hoehn. "The Economic Equivalency of Drained and Restored Wetlands in Michigan," *American Journal of Agricultural Economics* 84:1355-1361, 2002.
68. Horan, R., C. Perrings, F. Lupi, and E. Bulte. Biological pollution prevention strategies under ignorance: The case of invasive species, *American Journal of Agricultural Economics* 84:1303-1310, 2002.
69. An, Li.,* F. Lupi, J. Liu, M. Linderman, and J. Huang, "Modeling the Switch from Fuelwood to Electricity: Implications for the Conservation of Giant Panda Habitat," *Ecological Economics*: 42(3): 445-457, 2002.
70. Coon, T.G., H. Campa III, A.B.Felix,* R.B. Peyton, S.R. Winterstein, F. Lupi, M. Schulz, and J. Sikarskie. "Farming Captive Cervids: A Review of Social, Economic, and Ecological Opportunities and Risks in Michigan and North America," *Transactions of the 67th North American Wildlife and Natural Resources Conference*, 251-268, 2002.
71. Jones, C.A., and F. Lupi. "The Effect of Modeling Substitute Activities on Recreational Benefit Estimates," *Marine Resource Economics*, 14(4), 2000.
72. Lupi, F., and P.M. Feather. "Using Partial Site Aggregation to Reduce Bias in Random Utility Travel Cost Models," *Water Resources Research*, 34(12):3595-3603, 1998.
73. Lupi, F., "Valuing the Effects of Water Quality on Recreational Resources: Discussion," *American Journal of Agricultural Economics*, 80:1039-1042, 1998.
74. Rubey, L.,* and F. Lupi. "Predicting the Effects of Market Reform in Zimbabwe: A Stated Preference Approach," *American Journal of Agricultural Economics*, 78:89-99, 1997.

75. Jayne, T.S., L. Rubey,* F. Lupi, D. Tschirley, and M.T. Weber. "Estimating Consumer Response to Food Market Reform Using Stated Preference Data: Evidence from Eastern and Southern Africa," *American Journal of Agricultural Economics*, 78:820-824, 1996.

In review, Revise and Resubmit Status

1. Roeling, C.,* V. Verdier and F. Lupi, *In review: revise and resubmit*, Valuing Goods Allocated via Dynamic Lottery. *Journal of the Association of Environmental and Resource Economists.*
2. Goeb, J.,* A. Dillon, F. Lupi and D. Tschirley, *In review: revise and resubmit*, Pesticides: What you don't know can hurt you. *Journal of the Association of Environmental and Resource Economists.*
3. Yang, H., F. Lupi, J. Zhang and J. Liu, *In review: revise and resubmit*, Uncovering the hidden costs of conservation to local communities. *Ecological Economics.*
4. Melstrom, R.,* C. Roeling,* L. Gupta, S. Miller, Y. Zhang and F. Lupi, *In review: revise and resubmit*, Economic damages from a worst-case oil spill in the Straits of Mackinac, *J. of Great Lakes Research.*
5. Lupi, F., Phaneuf, D., and R. von Haefen, *In review: revise and resubmit*, Best practice in recreation demand analysis, *Review of Environmental Economics and Policy.*
6. Srivastava, L., et al., *In review: revise and resubmit*, How will climate change affect provision and value of water from public lands in Southern California through the 21st century? *Agricultural and Resource Economics Review.*

Books/Chapters

1. Garnache, C., L. Srivastava, J. Sánchez, and F. Lupi. 2018. Recreation Ecosystem Services from Chaparral Dominated Landscapes: A Baseline Assessment from National Forests in Southern California. Chapter 10 in *Valuing Chaparral: Ecological, Socio-Economic, and Management Perspectives*, E. Underwood, H. Safford, N. Molinari and J. Keely, (Eds), Springer.
2. Yang, W.,* F. Lupi, T. Dietz, J. Liu, 2016. Dynamics of Economic Transformation. Chapter 9 in *Pandas and People: Coupling Human and Natural Systems for Sustainability*. Eds. J. Liu, V. Hull, W. Yang A. Viña, X. Chen, Z. Ouyang and H. Zhang, Oxford University Press, New York.
3. Liu, W.,* A. Viña, F. Lupi, W. Yang,* J. Liu, 2016. Energy Transition from Fuelwood to Electricity. Chapter 10 in *Pandas and People: Coupling Human and Natural Systems for Sustainability*. Eds. J. Liu, V. Hull, W. Yang A. Viña, X. Chen, Z. Ouyang and H. Zhang, Oxford University Press, New York.
4. Chen, X.,* W. Yang,* V. Hull, T. Dietz, K. Frank, F. Lupi, J. Liu, 2016. Social Capital and Social Norms Shape Human-Nature Interactions. Chapter 11 in *Pandas and People: Coupling Human and Natural Systems for Sustainability*. Eds. J. Liu, V. Hull, W. Yang A. Viña, X. Chen, Z. Ouyang and H. Zhang, Oxford University Press, New York.
5. Swinton, S., Jolejole-Foreman, C.,* Lupi, F., Ma, S.,* Zhang, W., Chen, H.* 2015. Economic Value of Ecosystem Services from Agriculture. Chapter 3 in *The Ecology of Agricultural Landscapes: Long-term Research on the Path to Sustainability*, Eds. S.K. Hamilton, J.E. Doll, & G.P. Robertson, Oxford University Press, New York. Pages 54-76.
6. Swinton, S., Rector, N., Robertson, G.P., Jolejole-Foreman, C.,* Lupi, F. 2015. Farmer Decisions about Adopting Environmentally Beneficial Practices. Chapter 13 in *The Ecology of Agricultural Landscapes: Long-Term Research on the Path to Sustainability*. Eds. S.K. Hamilton, J.E. Doll, & G.P. Robertson, Oxford University Press, New York. Pages 340-359.

7. Kaplowitz, M., and F. Lupi. 2010. Ecosystem Banking as a Quasi Market Approach to Conservation: Building on U.S. Wetland Banking Experience. In *Human Dimensions of Soil and Water Conservation: A Global Perspective*, ed. Ted Napier. Hauppauge, NY: Nova.

8. Kaplowitz, M.D., D. Ortega-Pacheco,* and F. Lupi. "Payment for Environmental Services and Other Institutions for Protecting Drinking Water in Eastern Costa Rica," in *Alternative Institutional Structures: Evolution and Impact*. (Sandra S. Batie and Nicholas Mercuro, Editors). London: Routledge Press. 2008.

9. National Research Council, *Endangered and Threatened Species of the Platte River*. National Academies Press, Washington D.C. 2005 (Contributing author).

10. Kaplowitz, M., F. Lupi, and J. Hoehn, "Multiple-methods for developing and evaluating a stated preference survey for valuing wetland ecosystems." Chpt. 24 In *Questionnaire Development, Evaluation, and Testing Methods*, (S. Presser, et al., eds). 503-524. Wiley:New Jersey. 2004.

11. Lupi, F., and D.B. Jester, "Uses of Resource Economics in Managing Great Lakes Fisheries," in *Sustaining North American Salmon: Perspectives Across Regions and Disciplines*, (W. Taylor, M. Jones, and K. Lynch, editors). American Fisheries Society: Bethesda, MD. pages 195-220. 2002.

12. Lupi, F., and J.P. Hoehn, "Case Study of a Travel-Cost Analysis: The Michigan Angling Demand Model," in *Revealing the Economic Value of Protecting the Great Lakes* (A. Cangelosi, ed.). Northeast Midwest Institute: Washington D.C., pages 111-120, 2001.

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14. Chen, H., F. Lupi and J. Hoehn. An empirical assessment of multinomial probit and logit models for recreation demand, in: *Valuing Recreation and the Environment: Revealed Preference Methods in Theory and Practice*, (C. Kling and J. Herriges, editors) Edward Elgar Publishing: Northhampton, MA. pages 141-162, 1999.

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Kaplowitz, M.K., and F. Lupi, "What wetland bankers think about mitigation banking," *J. Soil and Water Conservation: Tech Transfer Briefing*, 63(3):90A, 2008.

Wiener, J., et al., "The Madison Declaration on Mercury Pollution." *Ambio* 36(1): 62-65, 2007.

Swinton, S., and F. Lupi, "Ecosystem Services to Agriculture." Briefing paper, NSF Workshop on Valuing Ecosystem Services from Agriculture, 2005.

Lupi, F, M. Kaplowitz, J. Hoehn, M. Gibson, O. Arreola, Stated preferences for Great Lakes coastal wetland programs, *Benefits and Costs of Resource Policies Affecting Public and Private Land*, (S. Shultz), 2005.

Hoehn, J.P., F. Lupi, and M. D. Kaplowitz, "The Effects of Questionnaire Formats on Elicited Preferences and Values in Stated Preference Experiments," in *Benefits and Costs of Resource Policies Affecting Public and Private Land*, (D. McLeod), Western Regional Research Publication, 2004.

Wallmo, K., F. Lupi, R. Peyton and P. Bull, "Public and Hunter Trade-offs Between Deer Populations and the External Effects of Deer," in *Benefits and Costs of Resource Policies Affecting Public and Private Land*, (D. McLeod), Western Regional Research Publication, 2004.

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Jayne, T., F. Lupi, and M. Mukumbu, "Effects of Food Subsidy Elimination in Urban Kenya: An Analysis Using Revealed and Stated Preference Data," Agricultural Economics Staff Paper No 95-23, MSU, 1995.

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Lupi, F. (Chief Scientist, Economics), Gupta, L., R. Melstrom, S. Miller, C. Reeling and Y. Zhang. 2018. Estimating the amount of natural resource and other economic damages, public and private, that would result from a worst-case release. Chapter GI, in "Independent Risk Analysis for the Straits Pipelines", (Meadows, G, et al., 384 pages). Independent report of consortium of Michigan scientists commissioned by the State of Michigan, 2018.

Lupi, F., 2015. Overview of natural resource values potentially at risk from consequences of net-pen aquaculture, Report to Michigan DNR and MDARD, October 2015.

Weicksel, S., and F. Lupi. 2013. A review of the economic benefits and costs of reducing harmful algal blooms on Lake Erie. Report to International Joint Commission. East Lansing, MI: MSU.

Simoes, J., Lupi, Frank, Hayes, Daniel B., The collection, utilization and importance of angler human dimensions data: A survey of U.S. fisheries management agencies. Great Lakes Fishery Commission, 2008.

Bull, P., B. Peyton, and F. Lupi "The Effect of Bovine Tuberculosis Management Strategies and Outcomes on the Mobility of Michigan Deer Hunters: Identifying Factors Influencing Site Fidelity," Report to Wildlife Division, Michigan Department of Natural Resources, August, 2006.

Bull, P., S. Knoche, F. Lupi, R. Peyton, Michigan Deer Hunter Opinion Survey: Methods and Results, Mich. Department of Natural Resources and Dept. of Agricultural Economics, MSU, September, 2006.

Lupi, F., "Choice Modeling Analysis of Hunting Lease Survey Data," report to Wildlife Division, Michigan Department of Natural Resources, September, 2005.

Lupi, F., "Recreational Angling Benefits of Improved Quality on Kalamazoo River, Michigan," In: *Kalamazoo River Environment, Natural Resource Damage Assessment Stage I Reports*, Trustees Report, Michigan DEQ, Michigan Attorney General, U.S. FWS, and NOAA, Lansing, MI, March 15, 2005.

Lupi, F., "Economic Losses to Michigan Resident Anglers Due to Stocking Losses of Yearling Coho in Lake Michigan," confidential attorney-client work product, submitted to Michigan Department of Natural Resources and Michigan Attorney General, June 2004.

Wallmo, K.A., F. Lupi, R.B. Peyton, and P. Bull, "A Survey of Hunter and Public Attitudes Toward White-tailed Deer and Deer Management," Wildlife Division, Mich. DNR, 87 pages, Dec. 2003.

Heyboer, G., J. P. Hoehn, M. Kaplowitz and F. Lupi, *Perceptions of The General Public Toward Natural Resources: a Study of Wetland Issues*, Agricultural Economics Reports 601, Department of Agricultural Economics, Michigan State University, 2001.

Coon, T. G., et al. (includes Lupi), *Farming Captive Cervids in Michigan: A Review of Social, Economic, Ecological, and Agricultural Opportunities and Risks*, Report to the Michigan Department of Agriculture and the Michigan Department of Natural Resources, July, 2000.

Lupi, F., *Estimated Value of Commercial Fishing Licenses in Bays De Noc Michigan*, Confidential draft report to Michigan Department of Natural Resource, Fisheries Division and Attorney Generals Office of the State of Michigan, February, 2000.

Lupi, F., *Rule 26 Report: US v. Michigan, The Economic Value of Recreational Fishing in Certain Treaty*

Waters of Michigan, Expert witness report to Attorney Generals Office, State of Michigan in support of U.S. et al v State of Michigan et al: M26-73, 93 pages, December 8, 1999.

Hoehn, J. P., T. Tomasi, F. Lupi, and H. Z. Chen, *An Economic Model for Valuing Recreational Angling Resources in Michigan,* Report submitted to the Michigan Department of Environmental Quality and Michigan Department of Natural Resources, Department of Agricultural Economics, Michigan State University, December 1996.

Lupi, F., R.L. Farnsworth, and J.B. Braden, *Improvement of Lake Water Quality by Paying Farmers to Abate Nonpoint Source Pollution*, research report 210, Illinois Water Resource Center, 1988.

Theses

Lupi, F., *Exact and Approximate Welfare Measures in the Repeated Random Utility Model with an Application to Valuing Great Lakes Fish*, Ph.D. dissertation, University of Minnesota, 1997.

Lupi, F., *An Economic Analysis of Sediment Control Policies: Apple Canyon Lake, Illinois*, M.S. thesis, University of Illinois, 1988.

Published Abstracts

Eight paper abstracts published in the *American Journal of Agricultural Economics.*

PRESENTATIONS

(full list available upon request)

Presentations by Lupi at Professional Conferences, Workshops or Universities: 134 Excluding extension/outreach presentations

Poster Presentations: 57

Papers Discussed by Lupi at Professional Meetings: 19

Presentations made by a Coauthor: over 150

GRANTS

Competitive Grants: (As PI/co-PI: $15.3 mil total; Econ/Soc.Sci. share $8.2 mil; Lupi share $4.8 mil)

Lupi, F., *Economics of Elk Management*, MDNR, Wildlife Division, 2017-2021, $216,700.

Sohngen, B, and F. Lupi, *Valuing Lake Erie beaches and the impact of impairments on beach users*, Ohio Sea Grant, 2018-2019, $118,411.

F. Lupi, J. Herriges, C. Garnache, J. Stevenson, D. Hyndman and B. Basso, *Linking Agricultural Nutrient Pollution To The Value Of Freshwater Ecosystem Services*, USDA NIFA, Oct 2016-Sept 2019, $500,000.

F. Lupi, J. Herriges, B. Basso and C. Garnache, *Behavioral economics of phosphorus use*, USDA NIFA, Oct 2016-Sept 2020, $250,000.

Steiner, et al., *Enhancing sustainability in coastal communities threatened by harmful algal blooms by advancing and integrating environmental and socio-economic modeling*, National Science Foundation, 2016-2019, Lupi's MSU portion $311,326.

Herriges, J., F. Lupi, J. Stevenson, *An Integrated Valuation Model Linking Nutrient Reductions to Changing Ecosystem Services in Freshwater Systems*, USEPA STAR Grant, 2016-2019, $800,000.

Lupi, F., S. Miller, *Independent Risk Analysis for the Straits of Mackinac*, MTU subcontract, 2018, $46,013.

Lupi, F., *Economic consequences of Asian carp establishment in the Great Lakes Basin*, US ACOE; Sept 2016-September 2017, $108,000.

Finnoff, D., Lupi, F., E. Rutherford, *Forecasting biological and economic impacts of aquatic invasive species in Lake Michigan*, Great Lakes Fishery Trust; Oct 2015-Nov 2018, $249,000

Lupi, F., *Statewide angler survey*, MDNR, Fisheries Division, 2015-2020, $320,555.

Lupi, F., J. Herriges, C. Garnache, J. Stevenson, *Ecological-Economics of freshwater nutrient pollution*, MSU Water Cube, Office of Vice Pres. For Research, 2015-17, $80,000.

Lupi, F., *License purchasing behavior & recreational participation*, MDNR Fish. Div., 2014-5, $17,000.

Lupi, F., *Angler Survey for Great Lake Management Planning*, MDNR Fish. Div. 2014, $17,000.

Bartholic, J. & Lupi, F. *The potential for incorporating economics into Great Lakes Tributary Model decision support tools*. USGS/ACOE Planning Grant, April-December 2014, $29,073.

Garnache, C., & Lupi, F., *Valuing Ecosystem Services in Southern California's Fire-Prone Landscapes*, USDA – Forest Service, May 30, 2014 - June 30, 2018, $250,000.

Stevenson, J., and F. Lupi, *Integrating indicators of ecological condition and services into a policy framework*, EPA, 2010-2014; allocation to date, $1,410,000.

Lupi, F., *Michigan trout angler survey*, MDNR Fisheries Div./Trout Unlimited. 2012-2014, $88,500.

Kashian, D, et al (Lupi is lead PI of social science), *Where People Meet the Muck: An Integrated Assessment of Beach Muck and Public Perception at the Bay City State Recreation Area, Saginaw Bay, Lake Huron*, Michigan Sea Grant, 2014-2016, $149,994.

Lupi, F., *Great Lakes Beaches: Where Water Quality Meets the Economy*, MAPPR Project, 2013-2016, $25,000.

Lui, Lupi, Hyndman, et al, *Sustainable Water Adaptation Network*, MSU ESPP/Water Center planning grant, 2012-2014, $100,000.

Lupi, F., *Statewide angler survey*, Michigan Dept. of Natural Resources, Fisheries Division, 2010-2015, $336,000.

Esselman, Hyndman, Lupi & Medina, *From Ridge to Reef: Adaptation to Climate Change in Belize*, MSU GenCen Planning grant, 2013-2014, $10,500.

Lupi, F., *Great Lakes angler preferences survey*, Michigan Dept. of Natural Resources, Fisheries Division, 2010-2013, $17,200.

Lupi, F., *Evaluation of the Economic Impacts of Algal Blooms in Lake Erie*, International Joint Commission. Type: Contract Amount awarded: $24,250. 2012-2013, $25,000.

Lupi, F., *Evaluation of Beach Advisories Through Smartphones – myBeachCast*, Great Lakes Commission, 2011-2012, $10,000.

Lupi, F., *Assessment of Human Service Impacts for Tittabawassee River and Saginaw Bay Watershed*, 2010-2015, $166,000.

Lupi, F., *Values and demand for ecosystem goods and services*, MAES, 2009-2013, $130,000.

F. Lupi (co-PI, social science lead), and M. Kaplowitz, *Adaptive Integrated Framework (AIF): a new* *methodology for managing impacts of multiple stressors in coastal ecosystems*, part of $4,618,100 grant to Great Lakes Environmental Research Lab from NOAA; Social science subcontract of $545,000 for Oct. 2007 - Sept. 2012, $545,000.

Lupi, Frank, *Black Bass Survey Add-on*, MDNR, Fisheries Division, 2007-2008, $14,000.

Wolf, C., and F. Lupi, *Record Systems Choice Model*, MAES Project Green, 2008-09, $20,000.

Liu, J., F. Lupi, M. Walters, and K. Hall. *Integrating ecology and economics for managed forest landscapes: A systems approach*, USDA NRI, Managed Ecosystems, 2006-10, $498,939.

Lupi, F., M. Kaplowitz, and R. Horan, *Economics and Policy of Environmental and Natural Resource Restoration*, Environmental Research Initiative, ESPP, MSU, March 2006-08, $77,906.

Swinton, S., F. Lupi, and P. Robertson, *Ecosystem Services from Low-input Cropping Systems: Incentives to Produce Them and Potential to Abate Climate Change*, Emerging Research Area Proposal, ESPP, MSU, March 2006-08, $55,000.

Lupi, Frank, D. Hayes, and Z. Su, *A state-wide survey of Michigan's licensed anglers*, Michigan Dept. of Natural Resources, Fisheries Division, 2006-2011, $150,000.

Lupi, Frank, *Economics of the Lake Michigan Recreational Fishery*, Great Lakes Fishery Trust, 2006-10, $253,584.

Lupi, Frank, and R. Horan, *Economic Summit on Lake Michigan Invasive Species*, Great Lakes Fishery Trust, 2006-7, $19,691.

Swinton, S., F. Lupi, and G.P. Robertson, *Agents of Change: Ecosystem Services from Low-input Cropping Systems: Incentives to Produce Them and Value of Consuming Them*, National Science Foundation, 2005-10, $399,999.

Kaplowitz, M.K, and F. Lupi, *Environmental Attitudes and Values*, Honors Research Grant, Honors College, MSU, 2006-7, $5,500.

Hoehn, J., M. Kaplowitz, and Frank Lupi, *The Stability of Values for Ecosystem Services: Tools for Evaluating the Potential for Benefits Transfers*, EPA STAR Grant, $235,772, April 2004 to 2008

Lupi, F. and S. Thayer, *Collecting Angler Behavior Data from Great Lakes Creel Surveys*, Great Lakes Fishery Commission, Jan 2005-June 2008, $33,005.

Jones, M. J. Liu, K. Scribner, and F. Lupi (w/D. Bruggeman), *Trading Habitat Patches within an Endangered Metapopulation: Incorporating the Role of Landscape Context and Uncertainty in Decision Making*. Strategic Environmental Research and Development Program, US Department of Defense, 2006, $100,000.

Kaplowitz, M., F. Lupi, and J. Hoehn, *Non Market Valuation and Public Trade-Offs for Great Lakes Coastal Wetland Preservation and Restoration*. Special Project Grant, Land Policy Program, Michigan State University, July 2005-June 2006, $19,183.

Kaplowitz, M., and F. Lupi, *Non Market Valuation and Public Trade-Offs for Great Lakes Ecosystem Preservation and Restoration*, Michigan Agricultural Experiment Station, 2005-6, $30,000.

Lupi, F., and R.B. Peyton, *Michigan Deer Hunters' Mobility, Demand for Hunting Sites and Economic Value*, Michigan Department of Natural Resources, Wildlife Div., 2004-6, $60,496.

Kaplowitz, M., F. Lupi, and J. Hoehn. *Non Market Values and Demand for Market-Mechanisms for Great Lakes Coastal Wetland Preservation and Restoration*, MSU Land Policy Special Projects Grant, 2004-5, $11,000.

Liu, Jianguo , Frank Lupi, and Michael Walters, *Integrating Ecology and Economics for Managed Forest Landscapes*, USDA NRI Managed Ecosystems, September 2002 to August 2005, $240,000.

Lupi, Frank, *Applications of the Recreational Angling Demand Model*, U.S. Fish and Wildlife Service, March 2002 to March 2003, $5,817.

Walters, Michael, Frank Lupi, and Jianguo Liu, *Integrating Ecology and Economics for Managed Forest Landscapes*, McIntire-Stennis Program/MAES, 2002-3, $49,000.

Kaplowitz, Michael, Frank Lupi and John Hoehn, *Estimating Nonmarket Values for Great Lake Coastal Wetlands*, Michigan Sea Grant College Program, March 2001 to December 2004, $139,000.

Horan, Richard, and Frank Lupi, *Economics of Policy Options for Controlling Aquatic Nuisance Species in the Great Lakes*, Michigan Sea Grant College Program, March 2001 to March 2003, $86,000.

Lupi, Frank and Ben Peyton, *Attitudes, Behavior, and Effort of Hunter's in Bovine TB Areas of Michigan*, Michigan Agricultural Experiment Station, October 2000 to September 2004, $105,000.

Kaplowitz, Michael, Frank Lupi and John Hoehn, *Identifying Nonmarket Values for Great Lake Coastal Wetlands*, Michigan Sea Grant College Program, March 2000 to March 2001, $30,000.

Liu, Jianguo, Frank Lupi, and Michael Walters, *Ecological and Economic Effects of Forest and Wildlife Management: Toward Holistic Management across Landscapes*, Michigan Department of Natural Resources, Wildlife Division, 2000-2004, $244,200.

Winterstien, S., H.R. Campa III., K.Millenbah, R.B. Peyton, and Frank Lupi, *Potential of Deer Population Management Using an Ecosystem Management Paradigm*, Michigan Department of Natural Resources, Wildlife Division, August 1999 to August 2004, $451,694.

Hoehn, John P., Frank Lupi, and Michael Kaplowitz. *Web-Based Methods for Valuing Wetland Services*, Joint NSF/EPA program: Decision Making and Valuation for Environmental Policy, December 1999 to November 2003, $227,759.

Hoehn, J.P., M.K. Kaplowitz, and Frank Lupi. *Economic Equivalency of Wetland Habitats: Demand-Based Methods for Wetland Banking in Michigan*, Michigan Great Lakes Protection Fund, June 1999 to May 2003, $178,813.

Lupi, Frank, *A Profile of Michigan Anglers: Preferences, Market Segments and Expenditures*, Michigan Department of Natural Resources, Fisheries Division, October 1999 to September 2004, $57,942.

Lupi, F. and J. Hoehn, *Value Estimation in Recreational Demand Models with Heterogeneous Trip Types*, Michigan Department of Environmental Quality, 2000 to 2001, $45,365.

Rutherford, E., M.R. Moore, F. Lupi and J.P. Hoehn, *Ecological and Economic Consequences of Hydropower-Related Watershed Restoration in Great Lakes Tributaries*, Michigan Sea Grant College Program, May 1999 to May 2001, $139,665.

Hoehn, John P., Frank Lupi, and Sandra S. Batie, *The Potential Economic Damages of Ruffe in the Great Lakes*, National Sea Grant College Program, Sept. 1997 to February 2001, $148,719.

Moore, M.R., and E. Rutherford (University of Michigan PIs), and J. Hoehn and F. Lupi (Michigan State University PIs), *Ecological and Economic Impacts of Watershed Restoration on Salmonid Productivity in Lake Michigan Tributaries*, Michigan Sea Grant, 1997 to 1999, $124,188.

Hoehn, John P., and Frank Lupi, *The Recreational Fishing Value of Sea Lamprey Control*, Great Lakes Fishery Commission, November 1996 to May 1998, $58,010.

Other grants (as collaborator)

Robertson, G.P., et al., "The KBS LTER Project: Long-Term Ecological Research in Row-Crop Agriculture," National Science Foundation's Long Term Ecological Research (LTER) program, 2005-2010 & 2010-2015 [Lupi was on the project as a co-Investigator (collaborator)].

Swinton, S. (LTER Co-PI), and F. Lupi (LTER Co-investigator), "Advancing Knowledge on Ecosystem Valuation," Collaborative Social Science LTER Supplemental, DEB-9810220 add-on, National Science Foundation, $37,258 for workshop in Oct. 2005.

Selected Contracts

In addition to above, about 50% of MSU faculty salary has been paid under annually renewable, performance-based contracts from the Michigan Department of Natural Resources (25% Fisheries Division, 23-25% Wildlife Division) every year from 1999-2019.

OUTREACH/EXTENSION

Lupi is the Fisheries and Wildlife Management Economist in the Department of Agricultural Food and Resource Economics and the Department of Fisheries and Wildlife. Lupi works within the Partnership for Ecosystem Research and Management (PERM) program, a cooperative agreement between Michigan State University, the Michigan Department of Natural Resources (DNR) and other Great Lakes agencies.

- Fisheries Division: I have provided consultations, economic evidence, and social science expertise for numerous natural resource damage assessments, valuation of commercial fishing licenses for buy-back purposes, sport/commercial fish allocations, ITQs in the Great Lakes, benefit transfers, valuation of fish kills, economic effects of hydropower relicensing, development of angler survey programs, enhancing angler data collected from creel surveys, working group on using license database for marketing, and license demand and elasticity.
- Wildlife Division: I have provided consultations and economic evidence to inform issues such as economic feasibility and growth potential of deer and elk farming, economics of managing wildlife diseases, public and hunter preferences for deer herd sizes and their consequence, landowner participation in public hunting lease programs, quantifying hunter investments, valuing publicly-accessible hunting land, and cost-effective land acquisition for habitat restoration.
- Other Service to MDNR: I have helped the Department meet a range of economic and human dimensions needs, including serving on the Department-wide workgroup on economic analyses and data infrastructure, advising on economic benefits of trails, assisting Marketing and Outreach Division with survey and research designs and analyses, helping personnel and commissioners with use and understanding of economic impacts, and assisting on Director priorities such as impacts of aquaculture, prevention of Asian Carp, tribal treaty negotiations, and natural resource damage assessments (with Michigan Attorneys General Office, US Dept of Justice and other trustees).

In addition to outreach performed under PERM, Lupi delivers outreach on natural resource economics to other State, Federal and NGO audiences in Michigan and the Great Lakes region. My programming strives to bring economic reasoning and evidence to help shape decisions, and is delivered through frequent presentations, expert consultations and dissemination my and others research.

- Harmful Algal Blooms (HABs) in Lake Erie: I have consulted and provided literature reviews and evidence on the economic impacts of HAB to the Lake Erie Ecosystem Priority (LEEP) committee of the International Joint Commission (IJC) and recently testified to the commissioners themselves. I have also cooperated with Ohio State University extension on workshops to broader audiences.
- Agricultural Conservation: My expertise on agricultural conservation practice adoption and cost-effectiveness has been shared with Mich. Dept. of Agriculture and Rural Development, U.S. Army Corp of Engineers (ACOE), National Resource Conservation Service and other parts of USDA.
- Great Lakes Beaches: I have provided expertise and evidence on beach demand and value to Environmental Protection Agency Great Lakes Program Office, Great Lakes Commission (GLC), IJC, Michigan Dept of Environmental Quality (MDEQ), Michigan Office of the Great Lakes (OGL), NOAA Great Lakes Environmental Research Lab and Michigan Sea Grant. Economic facts and data I supplied were used in efforts to maintain funding for the BEACH Act
- Invasive Species: My expertise, applied research, and programming on invasive species such as Asian carp, sea lamprey and mussels in the Great Lakes has been sought and delivered to a wide range of state and federal agencies including ACOE, Great Lakes Fishery Commission, GLC, Great Lakes Panel on Aquatic Nuisance Species, MDNR, MDEQ, OGL, USDA, and the Michigan and National Sea Grant programs.

TEACHING

Courses taught:

Fall 2019, 2017, 2015, 2013, 2011, 2009, 2007, 2005, MSU, AFRE 823: Environmental Economics Methods (formerly AEC 891)

Fall 2015, 2008, Spring 2002, MSU, FW 893, Seminar: Economics of Fisheries, Wildlife and Ecosystems

Fall 2013, MSU, AEC 890, Independent Studies: Nested Logit Models

Spring 2010, MSU, AEC 890, Independent Studies: Meta-Analysis

Spring 2007: MSU, PRO200H: UG Honors Research Seminar: Environmental Attitudes and Values

Fall 2006: MSU, PRO200H: UG Honors Research Seminar: Environmental Attitudes and Values

Spring 2006, MSU, FW 893: Seminar: Invasive Species Ecology, Policy, and Management

Summer 2005, MSU, AEC 890: Independent Studies: Natural Resource Damages

Fall 2001, MSU, AEC 829: Economics of Environmental Resources

Spring 1996, MSU, AEC 923: Theory of Environmental Economics

Fall 1991: Instructor (TA in 1990), U. MN. AGEC 3610: Res. Develop. & Environmental Economics

Lectures in courses: (106 guest lectures)
ZOL 446: Environmental Issues and Public Policy (16 times, 2006-2019)
ZOL 446: Environmental Issues and Public Policy, Expert Panel (9 times 2009-2017)
FW 101: Fundamentals of Fisheries and Wildlife (Fall 2008, Spr & Fall 09, Spr & Fall 10, Spr & Fall 11)
FW 203: Resource Ecology (4 in 2001, 4 in 2002, 4 in 2003, 2 in 2004, 1 in 2005, 2 in 2006)
FW 204: Energy (Spring 2008)
FW 434, Human Dimensions of Fisheries and Wildlife Management (Spring 2004)
FW 479: Fisheries Management/Brenigan (Spring 2002, 2003, 2004)
FW 852: Systems Modeling and Simulation (Fall 2008, Fall 2000)
FW 893: Seminar, Conservation Planning (Fall 2001)
FW/MC 481: Global Issues in Fish and Wildlife (Spring 2005, 2018).
EEP 255: Ecological Economics (2014, 2 in 2015, 2016, 2 in 2017, 2 in 2018, 2019)
EEP 320: Environmental Economics (Spring 2001, 2002, 2003, 2004, 2005, 2006, 2015-16, 2018, 2019)
EEP/FIM/ABM 303: Economics of Decision Making (Spring, Fall 2016, Fall 2018).
RD 460: Natural Resource Economics (2 in Spring 2003, 2 in 2005)
RD 200, Introduction to Environmental Studies (Spring 2004)
AEC 923: Theory of Environmental Economics (Spring 1998)
AEC 829: Economics of Environmental Resources (2 weeks Fall 2002)
EC 345 Environmental and Natural Resource Economics (Northern Michigan U.; Fall 2002)
ENVIRON 375 Environmental and Resource Economics (U of Michigan; Winter 2006)
ELPS, High School Econ., Economics, the Environment, and You, You! 2nd & 4th hour, Nov 2014.
Nine others guest lectures in classes 1992-1997.

Presentations to Graduate Students (orientation & brown bags):
AFRE Grad. orientation: Overviews of program or ERE field, 1999, 2000-02, 2004-07, 2010, 2015-19.
AFRE Brown bag series: 2006, 2 in 2007, 2008, 2010, 2014.
FW Human Dimensions Brown Bag: Quantitative Choice Models, January 2010.

Graduate Student Committees: *Chaired (advisor) or Thesis Supervisor, MSU*: (4 current, 20 complete)

In progress

1. Hyunjung Kim, Ph.D., Agricultural, Food, and Resource Economics (chair) in progress
2. Austin Hunt, M.S., Agricultural, Food, and Resource Economics (chair) in progress
3. Gregory Boudreaux, M.S., Agricultural, Food, and Resource Economics (chair) in progress
4. Noah Link, M.S., Agricultural, Food, and Resource Economics (chair) in progress

Completed

1. Sophia Tanner, Ph.D. Agricultural, Food, and Resource Economics (chair), 2018
   Title: The cost of wildfires in heavily urbanized areas: measuring property value and recreational impacts in Southern California
   1st Employer: University of Arizona, Post-doc, Phoenix AZ.

2. Li Cheng, Ph.D., Agricultural, Food, and Resource Economics (chair), 2016
   Title: Measuring the value and economic impacts of changes in water quality at Great Lakes beaches
   1st Employer: Amazon, Research Scientist, Seattle WA.

3. Jody Simoes, Ph.D., Fisheries and Wildlife (chair), 2014
   Title: Segmenting Anglers By Lifestyles, Lake Types, And Management Preferences
   1st Employer: Michigan DNR, Research Director, Marketing and Outreach Div.

4. Jessica Klatt, M.S., Agricultural, Food, and Resource Economics (chair), 2014
   Title: Linked Participation-Site Choice Models of Recreational Fishing
   1st Employer: USDA NASS

5. Scott Knoche, Ph.D., Fisheries and Wildlife (chair), 2014
   Title: Discrete Choice Models of Hunting and Fishing in Michigan
   1st Employer: University of Maryland/Maryland DNR

6. Min Chen, PhD. Agricultural Economics, (chair) 2013.
   Title: Valuation of Public Great Lakes Beaches in Michigan
   1st Employer: Freddy Mac
   * *Best Dissertation Award, AFRE, 2013*

7. Max Melstrom, Ph.D. Agricultural Economics & Economics, (advisor), 2012
   Title: Three Essays in Resource Economics: Protecting Non-Use Values through Ecosystem Management and Estimating Recreational Demand To Determine Use Values
   1st Employer: Salisbury College (now Oklahoma State University)
   * *Best Dissertation Award, AFRE, 2012*

8. Scott Weicksel, M.S. Agricultural Economics, (chair) 2012
   Title: Measuring Preferences for Changes in Water Quality at Great Lakes Beaches Using a Choice Experiment
   1st Employer: The Neilson Company
   * *Best Thesis Award, AFRE, 2012*

9. Tim Komarek, M.S., Agricultural Economics, (thesis advisor) 2010
   Title: Essays on the Economics of Environmental Management and Green Reputation
   1st Employer: Ph.D. student at MSU

10. Huilan Chen, M.S. Agricultural Economics, (chair) 2010
   Title: Ecosystem services from low input cropping systems and the public's willingness to pay for them
   1st Employer: Ph.D. student at UM

11. Susan Chen, M.S. Agricultural Economics, (chair) 2010
   Title: Hedonic Valuation of Timber Stands in the Great Lakes Northern Forests
   1st Employer: Ph.D. student at UC Davis

12. Min Chen, M.S., Agricultural Economics, (chair) 2009.
   Title: Does economic endogeneity of site facilities in recreation demand models lead to statistical endogeneity?
   1st Employer: Ph.D. student at MSU

13. Jody Simoes, M.S. Fisheries and Wildlife (chair) 2009
   Title: Recreational angler surveys: Their role and importance nationally and the 2008 Michigan angler survey
   Awards: Best presentation award, GSO Symp. award, AFS student paper award, Ball fellowship
   1st Employer: Ph.D. student at MSU

14. David Gebben, M.S. Agricultural Economics, (Thesis supervisor), 2008
   Title: Attribute Based Modeling of Recycling Preferences at Michigan State University
   Awards: Best presentation award, GSO Symposium
   1st Employer: Ph.D. student at Colorado State University

15. Shaufique Fahmi Ahmad-Sidique, Ph.D., Agricultural Economics, (Co-chair), 2008.
   Title: Analyses of Recycling Behavior, Recycling Demand, and Effectiveness of Policies Promoting Recycling
   1st Employer: Asst. Prof., Dept. of Agribusiness and Information System, Universiti Putra Malaysia

16. Daniel V. Ortega-Pacheco, M.S. Agricultural Economics, (chair) 2007
   Title: Payment for Environmental Services in Eastern Costa Rican Watersheds: Institutions, Public Participation and Demand.
   Awards: Travel grants from AAEA foundation, CANR at MSU, and MSU Grad School Tinker Field Research Fellowship, CLACS, Lupi supervised
   1st Employer: Ph.D. student at Ohio State University

17. Scott Knoche, M.S. Agricultural Economics, (chair) 2006
   Title: Travel Cost Models of Deer Hunting in Michigan
   Awards: Best presentation FW GSO Symposium; LPI Best poster; AAEA Best poster runner-up
   1st Employer: Economist, Natural Pollution Funds Center, US Coast Guard

18. Laila Racevskis, Ph.D., Agricultural Economics, (chair) 2005
    Title: Preferences and Nonmarket Values for Multiple Attributes of Forest Ecosystems in Michigan's Upper Peninsula
    Awards: Environmental Science and Policy Fellowship; MSU Graduate School Fellowship
    1st Employer: Assistant Professor, University of Florida

19. Melissa Savaard (Gibson), M.S. Agricultural Economics, (chair) 2005
    Title: Preferences of Michigan Residents for Great Lakes Coastal Wetland Program Characteristics
    Awards: Lake Michigan Federation, Environmental Economics Fellowship; Wisconsin Coastal Management Program travel award; LPI Best Poster Award
    1st Employer: Research Coordinator, Land Policy Institute, MSU

20. Kristy Wallmo, Ph.D., Fisheries and Wildlife, (chair) 2003
    Title: Economic Choice Modeling: The Use of Social Preference Data to Inform White-tailed Deer management in Michigan
    Awards: Environmental Economics Fellowship
    1st Employer: Natural Resource Economist at NOAA/NMFS

Graduate Student Committee Member: (6 current; 42 complete)

In progress

1. Tian, Qi, Ph.D., Economics, in progress
2. Braeden Van Deynze, Ph.D. AFRE, in progress
3. Stephen Aguegboh, MS. AFRE, in progress
4. Ebenezer Ansah, PhD., CSUS, in progress
5. Bineeta Gurung, PhD, CSUS, in progress
6. Roland Ofori, Ph.D., EEPP, Michigan Technological University

Completed

1. Christine Bocci, Ph.D., Ohio State University
2. Nathaly Rivera, Ph.D. AFRE, 2018
3. Hongbo Yang, Ph.D., Fisheries and Wildlife, 2018
4. Cem Tekesin, MS. AFRE, 2018
5. Joe Nohner, Ph.D., Fisheries and Wildlife, 2017
6. Joey Goeb, PhD., AFRE, 2017
7. Elena Dulys-Nusbaum, MS., AFRE, 2015
8. Ebenezer Ansah, MS., CSUS, 2016
9. Ranjit Bawa, MS., AFRE, 2015
10. Leah Harris, Ph.D. AFRE, 2015
11. Felix Kwame Yeboah, Ph.D., CSUS, 2014
12. Carson Reeling Ph.D., AFRE, 2014
13. Maolong Chen, MS. AFRE, 2014
14. Noel Hayden, M.S. Agricultural Economics, 2014
15. Li Cheng, MS. AFRE. 2014
16. AnneWeir, M.S. Agricultural Economics, 2012
17. Shan Ma, Ph.D. Agricultural Economics, 2012
18. Wei Liu, Ph.D., Fisheries and Wildlife, 2012
19. Kyle Molton, M.S., Fisheries and Wildlife, 2012

20. Shan Ma, M.S. Agricultural Economics, 2009
21. Felix Kwame Yeboah, M.S., CARRS, 2009
22. Luis Flores, Ph.D., CARRS, 2009
23. Christine Jolejole, M.S., Agricultural Economics, 2009
24. Oscar Arreola, M.S., CARRS, 2007
25. Eli Fenichel, Ph.D., Fisheries and Wildlife, 2007.
26. Benjamin Gramig, Ph.D., Agricultural Economics, 2007.
27. Nigel Griswold, M.S. Agricultural Economics, 2006.
28. Douglas Bruggeman, Ph.D., Fisheries and Wildlife, 2005.
29. Deb Bailey, M.S., Resource Development, 2005.
30. Paul Steiner, M.S. Agricultural Economics, 2003
31. Arvin Vista, M.S. Agricultural Economics, 2003
32. Katherine Smith, M.S., Fisheries and Wildlife, 2003
33. Meegan Dorn, M.S., Fisheries and Wildlife, 2003
34. Melissa Koval, M.S., Fisheries and Wildlife, 2003
35. Ben Warolin, M.S., Agricultural Economics, 2003
36. Tsitsi Makombe, M.S., Agricultural Economics 2002
37. Brady Deaton, Ph.D., Agricultural Economics, 2002
38. Kadir Kizilkaya, Ph.D., Animal Science 2002
39. Steve Haesecker, Ph.D., Fisheries and Wildlife 2001
40. Lisna Utami, M.S., Agricultural Economics 2001
41. Karin Steffens, Ph.D., Agricultural Economics 1999
42. Tiffany Phagen, M.S. Agricultural Economics, 1996

Undergraduate Students (research mentor): (* = presentation at MSU annual UG Research Forum; ‡=presentation at a professional meeting)

1. Keegan Gendron,* Public support for and against water quality investments, 2018-19
2. Josh Knoll,* National Forest Visitation, 2018
3. Jonathon Siegle,*‡ Trout Angler Expenditures and Economic Impacts, 2013-2016
4. Jordan Altobeli, Glassons Scholar intern, 2014.
5. Kevin Adams, Beach Visitors in Michigan, (co-advisor with M. Kaplowitz), 2011
6. Tim Nance,* Environmental Improvements Survey Content Analysis, 2010
7. Patricia Thompson,* Angler Survey Themes and Tone Content Analysis, 2010
8. Jeremy Rapp, * Angler Survey Themes and Tone Content Analysis, 2010
9. Brendan Lamers,* GHG Attitudes Survey, 2010
10. Carolyn Gillen, ‡ Angler Survey Database and On-line Bibliography, 2008.
11. Brittany Blankenship,* Great Lakes Diversions, honors research project 2006-2007
12. Katherine Chumak,* Great Lakes Beach Use Survey, honors research project 2006-2007
13. Dani Giles,* Great Lakes Beach Use Survey, honors research project 2006-2007
14. Elizabeth Hoxie,* Great Lakes Beach Use Survey, honors research project 2006-2007
15. Lauren Jones,* Great Lakes Beach Use Survey, honors research project 2006-2007

Dozens of other undergraduate students employed by various research projects.

PROFESSIONAL ACTIVITIES

Professional Panels/Expert

NOAA Harmful Algal Bloom Planning Committee, 2019-present.
Council of Great Lakes Governors, Great Lakes Blue Accounting: Water Monitoring and Accounting Workgroup Member, (February 2014 - April 2014).
Great Lakes Futures Project, Economics expert and student project advisor, 2012-2013.
Human Dimensions Task Group, Lake Erie Committee, Member, 2010-2012.
National Academy of Science, National Research Council, Committee on Endangered and Threatened Species in the Platte River Basin, 2003-5.
NOAA/National Marine Fisheries Service, Social Science and Ecosystem Management Panel, 2004
Blue ribbon panel, Economic valuation of Great Lakes environmental benefits, NEMWI-NOAA, 1997-00
Green Infrastructure Advisory Panel, Land Policy Institute, MSU, 2008.
The Benefits of Restoring the Great Lakes Ecosystem, Brookings Institute expert panel, 2007.
Ecological & Economic Impacts of Ship-Borne Invasive Species in the Great Lakes, University of Notre Dame, Expert panelist/structured judgements, October 19, 2007
Socioeconomic and cultural costs of mercury pollution, International Workshop on Environmental Mercury Pollution, July 13-18, 2005, Madison, WI, and expert panel, 2005-6.
Expert witness, effects of zonal plans on recreational fishery value; lawsuit & negotiations on tribal fishing in Great Lakes (U.S., et al v State of Michigan, et al.M26-73) Oct. 1999-Aug. 2000.
Expert assistance, Michigan Department of Natural Resource, Fisheries Division, with assessment of commercial fishery license buyback plan including firm-specific valuations, February, 2000.
Expert testimony, Federal Energy Regulatory Commission, national hearings, Comprehensive Review of Hydropower Licensing (Docket PL01-1-000), January 11, 2001.

Meetings/Session Organization

Co-organizer (with J Bartholic) The Potential for Incorporating Economics into the Decision Support Tools: Workshop organized for ACOE, USGS and MSU IWR. October 17, 2014
Co-organizer (with R. Horan and M. Kaplowitz), Economics of Invasive Species Workshop, MSU Union, East Lansing, MI, October 8-9, 2007.
Organizer, Department Graduate Research Symposium, MSU, East Lansing, MI, January 19, 2007.
Facilitator, discussion of economic policy and research needs with policy & agency representatives, Economics of Invasive Species Workshop, MSU Union, East Lansing, MI, October 8, 2007.
Session co-organizer/moderator (with S. Swinton and P. Robertson), "Harvesting Ecosystem Services from Agriculture," AAAS Symposium Proposal, St. Louis, February 18, 2006.
Symposium lecture co-organizer (with Doug Schemske), Invasive Species Symposium, Michigan State University, East Lansing, May 13, 2005.
Workshop co-organizer (with LTER co-PIs: S. Swinton, P. Robertson, K. Gross, and S. Hamilton), National Science Foundation LTER Workshop: "Advancing Knowledge on Ecosystem Valuation," NSF-funded, invitation-only, workshop October 27-28, 2005, Brook Lodge Resort, MI.
Meeting organizer, 15th annual meeting of USDA Multistate Research Project W133, Benefits and Costs of Resource Policies Affecting Public and Private Land, Monterey, CA, February 17-20, 2002.
Session organizer, "Environmental and Natural Resource Economics," Western Regional Science Association/W133 joint session, February 19, 2002.
Session co-organizer (with John Whitehead), symposium "Economics of recreational fishing: applications, state-of-the-art, and research needs," 2000 American Fisheries Society, St. Louis, Mo.
Session co-organizer (with John Braden), principal paper session entitled "Environmental Economics of the North American Great Lakes," at 1998 Allied Social Science Association meeting, Chicago, IL; sponsored by AAEA and Association of Environmental and Resource Economists.

Discussion panel/invited participant

TERA Lower Passaic River Review Panel, Committee Member, 2012.

Panel member, PREISM, USDA ERS, Washington DC. October 23-24, 2008

Co-organizer, Economics of Water in the 21st Century, Workshop 2009.

Co-organizer, Economics of Water in the 21st Century, Workshop 2009.

Invited plenary panelist, 8th International Conference on Mercury as a Global Pollutant, Madison, WI. August 6-11, 2006.

Invited, Congressional Visits Day, Council on Food, Agriculture, and Resource Economics and Coalition for National Science Funding, Washington D.C. September 13-14, 2005.

Invited, St. Marys River Decision Analysis Workshops, Detroit MI, April 22-23, 1999 & East Lansing, MI, April 24-25, 2001.

Panel member, "Valuing Ecosystem Services" session, W133 meeting, Kauai, February 28, 2000.

Invited, Sea Lamprey International Symposium II and "Designing an optimal program" group, Sault Ste. Marie, MI, August 2000.

Facilitator of group discussions on ecosystem management at Michigan Department of Natural Resources, Wildlife Division's in-service training, Traverse City MI, March 20, 1999.

Invited, "Workshop on Choice Set Definition in Recreational Fishing Valuation Models," National Marine Fisheries Service, Silver Spring, MD, September 9-10, 1999.

Panel member, Great Lakes Economic Valuation Stakeholder' Forum, NOAA/NEMW, address public questions about valuation methods, Chicago, July 15, 1998.

Panel member, and discussion leader of topic "Trip Length Issues," at Travel Cost Method Workshop, NOAA's Damage Assessment Center, Jekyl Island GA, March 12, 1996.

Panel member, "Statewide Angler Surveys: A Case Study Perspective," symposium session, American Fisheries Society's annual meeting, Dearborn, August 1996.

Editorial service

Co-editor, Special Issue: Economics of Invasive Species, Resource and Energy Economics, 2009-10.

Co-editor, Special Issue: Ecosystem Services from Agriculture, Ecological Economics, 2007.

Associate editor, Resource Economics, North American J. Fisheries Management, 2001-02.

Editorial Board, Economics Research International, 2009-2017.

Peer reviews performed for the following journals

Australian J. of Agricultural and Resource Economics, Agriculture and Human Values, Agricultural and Resource Economics Review, AMBIO, American J. Agricultural Economics, Canadian J. of Agricultural Economics, Canadian Water Resources Journal, Choices, Coastal Management Journal, Conservation Biology, Conservation Letters, Contemporary Economic Policy, Ecological Economics, Ecology and Society, Economics Research International, Energy Economics, Environmental Management, Environmental Conservation, Environmental and Resource Economics, Environmental Science and Technology, Estuaries, European Review of Agricultural Economics, Forest Science, Human Dimensions of Wildlife, J. of Agricultural and Applied Economics, J. of Agricultural and Resource Economics, J. of American Water Resource Assoc., J. of Environmental Economics and Management, J. of Environmental Management, J. of Great Lakes Research, J. of Law, Economics and Organization, J. of Outdoor Recreation and Tourism, J. of Survey Statistics and Methodology, J. of Wildlife Management, Land Economics, Marine Resource Economics, North American J. of Fisheries Management, Public Opinion Quarterly, Society and Natural Resources, Resource and Energy Economics; Resources, Conservation, and Recycling; Water Resources Research, Wildlife Society Bulletin

Grant Proposal Review Panels

Technical review panel, USDA/NIFA, Environment, 2019.

Technical review panel, NSF Graduate Fellowships, 2013-2017.

Technical review panel, US EPA, Markets Mechanisms and Incentives, 2007.
Technical review panel, CALFED Ecosystem Restoration Grant Program, 2006.
Technical review panel, New York Sea Grant Program, 2006.

Review Research Proposals:
Federal: NOAA/NMFS Saltonstall-Kennedy Grants, USDA/NIFA, USDA/ERS Program of Research on Economics of Invasive Species Management, USDA/NRI Markets and Trade, USDA/NRI Managed Ecosystems, USDA/NRI Small Farms/Rural Communities, USDA/SBIR Rural & Community Development(Phase I and Phase II proposals), US EPA
Sea Grant: California Sea Grant, Delaware Sea Grant, Illinois-Indiana Sea Grant, Iowa Water Center, Michigan Sea Grant, Minnesota Sea Grant, National Sea Grant, New York Sea Grant, Northeast Sea Grant Consortium, Ohio Sea Grant, Wisconsin Sea Grant, Woods Hole Sea Grant
Michigan: Michigan Department of Natural Resources, Michigan Great Lakes Protection Fund, Michigan State University-VPRG, Michigan State University-Competitive Discretionary Funding Program, Michigan State University-Environmental Science and Policy Program, Michigan Agricultural Experiment Station, Michigan AgBioResearch, , Sustainable Michigan Endowed Project (W.J. Kellogg Foundation & MSU), University of Michigan-Water Grants
Misc: CALFED, California Department of Food and Agriculture, Minnesota Aquatic Invasive Species Research, University of Rhode Island Agricultural Experiment Station, University of Nevada-Reno Agricultural Experiment Station, Great Lakes Fishery Commission, Great Lakes Fishery Trust

Review Research Reports/Books:
Book Manuscript, Johns Hopkins Press
Book Manuscript, Perman Press
Book Manuscript, University of Michigan Press
California Department of Food and Agriculture, Economics of Invasive Species
International Joint Commission, SedPAC Committee
International Joint Commission, LOSL Study
Illinois Waste Management and Research Center, Illinois Dept. of Natural Resources
Michigan Department of Natural Resources, Fisheries Division
Michigan Department of Natural Resources, Wildlife Division
Michigan Sea Grant publication, Life of the Lakes
Michigan Sea Grant publication, "Northeast Michigan Integrated Assessment"
National Wildlife Research Center, USDA/APHIS
NOAA Coastal Oceans Program publication
US EPA, Phase II Rule, Clean Water Act §316B, EPA Environmental Benefits Analysis (review reports A1, D5, F5, A15, supporting docs and replicate data analysis), 2003.
Water Resources Research Institute, University of North Carolina
University of Michigan Water Center's Freshwater RFP

Professional meetings: reviewer, judge, programming:
American Agricultural Economics Assoc. (AAEA)
AAEA selected papers topic leader, Natural Resource Modeling and Valuation, 2005, 06
AAEA poster coordinator for Nat. Res. & Env. posters: 2003, 04, 05
AAEA selected paper review: 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2010, 2011, 2012, 2013
AAEA poster judge at meeting: 2001, 03
AAEA poster reviewer: 2002, 03, 04, 05
Agricultural Economics Graduate Research Symposium, Judge, February, 2007, 08
Fisheries and Wildlife Graduate Research Symposium, Judge, MSU Union, February, 2007
Invasive Species Symposium, Judge, Epply Center, MSU, 2006, 08.

Midwest Fish and Wildlife Conference, Presentation Judge, 2005
Northeastern Agricultural & Resource Economics Assoc., selected paper reviews: 2002, 04, 05
International Society for Natural Resources Management, selected paper reviews, 2016
USDA/ERS Ecosystem services valuation within USDA–Advancing the science, workshop reviewer 2018

Professional Societies Committees/Offices
USDA Regional Research W133: Secretary 1999-00, Vice-President in 2000-01, President 2001-02.
American Agricultural Economics Assoc., Publications Committee, 2017-19
American Agricultural Economics Assoc., Awards Committee, Extension, 2007-09
American Agricultural Economics Assoc., Professional Activities and New Products Committee, 2002.
American Agricultural Economics Assoc., Selected Papers Committee, 2005-6.
American Fisheries Committee, Ad hoc committee of Resource Policy Committee, 2006
Committee on Human Dimensions Research in Recreational Fisheries, American Fish. Soc., 1997-2010.
Midwest Fish and Wildlife Conference, Technical Committee, 2005
Western Regional Science Association, program committee, 2002

Other Universities: External promotion and tenure reviewer, 8 instances.

University/College Committees/Service (MSU):
Member, College Advisory Council, College of Agriculture and Natural Resources, 2018 & 2019
Elections Officer, College of Agriculture and Natural Resources, 2018
Member, MSU Water Research Advisory Com. – CANR elected rep, 2014-2016
Member, MSU Water Research Advisory Com., Survey subcom., 2014-2016
Chair, College Graduate Com., College of Agriculture and Natural Resources, 2014
Member, University Fellowship Com, Michigan State University, 2014.
Member, College Graduate Com., College of Agriculture and Natural Resources, 2013
Member, University Fellowship Com, Michigan State University, 2013.
Member, College Graduate Com., College of Agriculture and Natural Resources, 2012
Member, University Fellowship Com, Michigan State University, 2012.
Chair, Reorganization Task Force, AFRE, College of Agriculture and Natural Resources, 2010
Member, Reorganization Task Force, AFRE, College of Agriculture and Natural Resources, 2009
Member, Blue Ribbon Panel on MSU's Water Research agenda, 2010
Member (alternate), College Advisory Council, College of Agriculture and Natural Resources, 2010
Member (alternate), College Advisory Council, College of Agriculture and Natural Resources, 2009
Member, University Hearing Board, Michigan State University, 2008, 2009, 2010
Member, College Advisory Council, College of Agriculture and Natural Resources, 2006
Chair, College Awards Committee, College of Agriculture and Natural Resources, 2005
Chair, Exam Committee, Environmental and Resource Economics Specialization, 1999-06
Elections Officer, College of Agriculture and Natural Resources, 2006
Member (Alternate), College Advisory Committee, College of Ag. and Nat. Resources, 2004, 2005
Member, Coordinating Committee, Environmental and Resource Economics Specialization, 1999-.
Member, Exam Committee, Environmental and Resource Economics Specialization, 2007-.
Member, advisory committee, MSU Environmental Policy Speaker Series, Fall 2000.
Member, Captive Cervidae Steering Committee, MSU ad hoc university committee, 1999-2001.
Member, ad hoc university coordinating com. on bovine tuberculosis in Michigan, MSU, 1999-2000.

Departmental Committees/Service (MSU):
Member, Department Advisory Committee (elected), AFRE, 2019
Chair, Awards Committee, Fisheries and Wildlife, 2019
Member, Economics Comprehensive Exam com., AFRE, 2016-2018

Member, Promotion and Tenure com., AFRE, 2018
Chair, Strategic Planning Committee, ERE Field, AFRE, 2015-16
Chair, Department Advisory Committee (elected), AFRE, 2015
Chair, Department Advisory Committee (elected), AFRE, 2014
Member, Endowed Professor Search Com. (Smith Chair), AFRE, 2013-14.
Member, Faculty Mentoring Com., C. Garnache, AFRE, 2013-.
Chair, ERE comprehensive field exam committee, AFRE, 2013.
Member, Assistant Professor Search Com. (ICT4D), AFRE, 2013.
Member, PhD Dissertation awards committee, AFRE, 2014, 2018
Chair, Assistant Professor Search Com. (Water), AFRE, 2012.
Member, Academic Program Review Committee, FW, 2013.
Member, Awards Committee, AFRE, 2012.
Chair, Department Advisory Committee (elected), AFRE, 2003-4.
Chair, Graduate Policy Committee, Department of Agricultural Economics, 2005, 06.
Member, Department Advisory Committee (elected), AFRE, 2009-10.
Member, Department Advisory Committee (elected), AFRE, 2002-3.
Member, Dept. Chairperson Search Committee (elected), AFRE, 2002.
Member, Faculty Mentoring Committee, R. Shupp, AFRE, 2008-.
Member, Assistant Professor Search Committee, AFRE, 2008.
Member, Asst/Assoc. Professor Search Committee, AFRE, 2007-8.
Member, Ad hoc Committee on Web Page, AFRE, 2008.
Member, Ad hoc Committee on Research Briefs, AFRE, 2011.
Member, Admissions Committee, Dept. of Agricultural Economics, 2005-6, 07-08, 11-12, 18, 19.
Member, Awards Committee, Department of Agricultural Economics, 2004.
Member, Assistant Professor Search Committee, Department of Agricultural Economics, 2004-5.
Member, Graduate Policy Committee, Department of Agricultural Economics, 2000, 2001, 2005.
Member, Graduate Orientation Committee, Department of Agricultural Economics, 2000, 2008.
Member, Economic analysis comprehensive exam committee, Dept. of Economics, 2000.
Member, Ph.D. Thesis Selection committee, Dept. of Agricultural Economics, 1999-2000.
Member, Assistant Professor Search Committee, Dept. of Agricultural Economics, 1999.
Chair, ERE comprehensive field exam committee, Dept. of Agricultural Economics, 1999, 2005.
Member, ERE comprehensive field exam com., Dept. Ag. Economics, 1996, 97, 00, 07, 10, 10, 11.
Graduate Student Representative, Priorities Committee, Applied Econ, Univ. of Minnesota, 1991-92.

Awards/Honors
William J Beal Outstanding Faculty Award, Michigan State University, 2018.
Excellence in Service Award. Sponsor: AFRE, MSU. 2016.
Outstanding Graduate Student Advising. Grad. Coordinator's Award. Sponsor: AFRE, MSU. 2016.
Distinguished Extension/Outreach Award. Sponsor: AFRE, MSU. 2011.
Outstanding Scientific Paper Award, National Academy of Sciences and Technology, Philippines, 2008.
Best paper presentation award, Socioeconomics Section, American Fisheries Society, 2008.
Faculty Award, Land Policy Institute, Poster presentation at Land Use Summit, 2007.
Meredith F. Burrill Award, Assc. of Am. Geographers, 2006 (interdisciplinary team award)
Poster presentation award, honorable mention, AAEA Annual meeting, 2017.
Poster presentation award, 3rd place, AAEA Annual meeting, 2006.
Poster presentation award, honorable mention, AAEA Annual meeting, 2006.
Best of Show Poster Presentation Award, Land Policy Program, 2005.
Member of Gamma Sigma Delta, Honor Society of Agriculture, 1993.
Director of Graduate Studies Honor List, Applied Economics, University of Minnesota, 1989-92.

Outstanding M.S. Thesis, Department of Agricultural Economics, University of Illinois, 1988.
Kenneth E. Grant Research Scholarship, Soil and Water Conservation Society, 1987.

Advisor or project advisor to students that received the following awards:
- Best MS Thesis, MSU AFRE (2012)
- Best PhD Dissertation Award, MSU AFRE (2012, 2013).
- Best Student Presentation (2004, 2006, 2008, 2009, 2010, 2012, 2014)
- Best Student Poster (2004, 2006)
- Tinker Field Research Grant, MSU (2006)
- Research Enhancement Award, MSU (2006, 2017)
- Student travel awards (2003, 2004, 2005, 2006, 2007, 2013, 2014, 2017)
- Student fellowships (13 awards: 2001, 2003-11, 2013-15)
- U.G Student, $2,000 Undergraduate Research Award, CANR URP (2014-5)
- U.G. Student, MSU AFRE, Environmental Economics Faculty Award (2018, 2019)
- Harvard Giorgio Ruffolo Post-Doctoral Fellowship in Sustainability Science (2010)

Committee member for students that received best dissertation or theses awards:
- Best MS Thesis, MSU AFRE (2009, 2018)
- Best PhD Dissertation Award, MSU AFRE (2009, 2012, 2018).
- Gill-Chin Lim Award for Outstanding Dissertation in Global Studies 2011

Appendix 13 D

40 CFR 122.21(r)(13) – Peer Review

MDNR Approval of Peer Reviewers

From: Hackler, Pam
To: Kohlbusch, Meghan
Cc: Giesmann, Craig J; Abbott, Michael
Subject: [EXTERNAL] Labadie Peer Reviewers
Date: Monday, June 03, 2019 3:11:15 PM

EXTERNAL SENDER

Good afternoon Meghan,

Thank you for the submission of the three curricula vitae (Barnthouse, Cuchens, and Lupi) as the proposed peer reviewers for the Labadie 316(b) studies. The studies requiring peer review, at 40 CFR 122.21(r)(10) Comprehensive Technical Feasibility and Cost Evaluation Study, (r)(11) Benefits Valuation Study, and (r)(12) Non-Water Quality Environmental and Other Impacts Study, appear to be wholly appropriate for these three reviewers.

In response to your request for a timely endorsement, an email is being sent. If Ameren requires a letter of approval, please let me know. It is our understanding, 40 CFR 122.21(r)(13) reviewers do not require official approval from the permitting authority. Thank you for the opportunity to review their curricula vitae.

Thanks,
Pam

Pam Hackler

Pam Hackler, Environmental Scientist
Missouri Department of Natural Resources
Water Protection Program; Industrial Wastewater Unit; NPDES Permitting
Tel: 573-526-3386
Email:pam.hackler@dnr.mo.gov